Tailoring Concurrent Engineering to Small Companies

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Abstract

This thesis presents the findings of a four year collaborative programme between Middlesex University and Rimmer Brothers, a small medical device manufacturer. During this time the author and other associates have introduced to the company a new approach to product design based on the principles of Concurrent Engineering (CE). A review of CE case studies reveals how its usage is mainly confined to large organisations, despite offering universally applicable advantages.

In applying such ideas to a company of only ~50 employees, it has become clear that a number of 'environmental factors' including culture, product complexity and available resources influences the implementation and success of CE schemes. Most notably, resource shortages diminish the effects of lead time compression. Use of a modified implementation for the development of several new products has yielded cost reductions approaching 50% - results comparable with large companies. This demonstrates that if due consideration is given to these factors, then CE can be seen to be a powerful and effective tool in any size of organisation.

RB
rimmer brothers

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List of Abbreviations

Acronym	Description	Page First Referenced
BET	Biased Environment-Tool analysis	97
BPRE	Business Process Re-Engineering	30
CAD	Computer Aided Design	25
CAM	Computer Aided Manufacture	25
CE	Concurrent Engineering	17
COP	Company Operating Procedure	50
DFA	Design For Assembly	26
DFM	Design For Manufacture	26
DFMA	Design For Manufacture and Assembly	26
DFR	Design For Recycling	23
DFX	Design For 'X'	23
EDM	Electronic Data Management	25
MDT	Multi-Disciplinary Team	24
QFD	Quality Function Deployment	27
RP	Rapid Prototyping	25
SWOT	Strengths, Weaknesses, Opportunities & Threats	30
TCS	Teaching Company Scheme	40

Statement of Candidate's Contribution

The work presented in this thesis is the result of a collaborative programme involving representatives from Middlesex University and Rimmer Brothers. The work was conducted by two associates who were employed consecutively for 12 months and 30 months respectively. The majority of the work presented here has been that of the candidate, specifically including:

- Literature review
- Historical account of the company
- Analysis of company weaknesses
- 12 month review of CE scheme and subsequent modification / implementation
- Product development (excluding phase one development of cautery handles)
- Post-analysis of scheme
- Generation of BET analysis tool

Credit for the following work is accorded to the initial associate Mike Packham:

- Initial creation of CE team
- Market review of existing products leading to development prioritisation
- Phase one development of light and heavy duty cautery handles

Acknowledgements

I would like to acknowledge the support of all those involved in this programme, including my University supervisors Tony White, Raj Gill and Mehmet Karamanoglu all of whom have had occasion to provide encouragement and much needed advise; my company supervisor Alastair Ross who placed faith in the programme, and also my own abilities from the outset; and all those who have suffered my unorthodox approach to deadlines.

1 - Introduction to the Climate of Change

The aim of this thesis is to discover whether concurrent engineering can be applied to small companies in order to improve the efficacy of their design process. A historical perspective will be presented which explains the origins and need for such a methodology, before proceeding in Chapter 2 to a detailed description of concurrent engineering and its adoption in large companies. Chapter 3 will introduce Rimmer Brothers, the company involved in this research, and show that the problems they face of *long lead times* and *poor product design* are similar to those commonly tackled by concurrent engineering in larger organisations. The remainder of the thesis presents the methods, results and conclusions of three years work with the company testing the hypothesis.

1.1 A New Industrial Revolution

Modern management methodologies, of which concurrent engineering is one, are intended to improve the competitiveness and consequent profitability of a company. Today competition is fierce and more global in nature than ever before. Just as the mass-production revolution at the start of the last century fundamentally changed the way industries worked, this first chapter will illustrate how the information revolution we find ourselves in at the beginning of the 21st century is proving equally significant, and how important it is for companies of all sizes to adapt in order to remain competitive.

1.2 A History of Industry

To help understand the world we live in today, and to look to the future, it is helpful to first appreciate the past. The history of the last 150 years provides not only the foundations and explanation of today's world, but can also help us to predict what the next millennium will hold.

For better or worse, the most significant changes during this time have been in the world of manufacturing. Indeed, little more than a century ago the meaning of the term manufacturing was itself notably different, and more akin to its literal derivation, to make by hand. But since the manufacturing revolution, the nature, availability and extent of manufactured goods has changed the face of the planet out of all recognition. Its effects have altered every facet of human existence, from lifespan to literacy; from political direction to pollution, from community size and interaction to global discrepancies in quality of life. To understand how today's society has evolved provides the first step towards knowing how best to compete and survive in it, and is therefore where this thesis will begin.

1.2.1 19th Century Acceleration

Following the industrial revolution around the turn of the 19th century, the way of life for those affected irreversibly changed, as people migrated from the country to take up jobs in what would justifiably be called the satanic mills of Britain's cotton industry. In the period from 1801 to 1861, the percentage of the occupied population in agriculture fell from 35.9% to 18.7%, whilst there was a corresponding increase in the numbers employed in manufacturing from 29.7% to 43.6%[1].

Such an influx of people, all desperate for a job just to survive led to high levels of unemployment (often as high as 60%[2]) and meant that conditions for workers were very poor, but the jobs were still regarded as a step up from the increasing poverty of the farming sector. As entrepreneurs explored the possibilities of volume production, it was very easy for them to undercut domestic manufacturing such as spinning[3]. At this time there was little need to consider the efficiency of the process because demand was so high that just to be in business guaranteed profit. A victim of its own success however, increasing industrialisation led to overproduction in some sectors which would begin to cause problems before the end of the 19th century:

> "The crisis of the 1870's, triggered by several bank failures in the United States, stemmed from a growth in industrial output that often exceeded demand"[4]

As more countries became industrialised, and more companies entered the arena, competition began to affect sales - a factor that has been part of industry ever since.

1.2.2 Management Pioneers

Thus, the influence of competition depends first of all on the ratio of supply to demand. Whilst demand outstrips supply, the relative merits of one product over another are of little importance. Similarly, there is no impetus to do anything more than set a price that the market will support, and sell products at the rate they are produced. Conversely, people started to realise that as this ratio began swinging the other way, more cunning was needed to protect profit margins, and see off competitors. The concept of efficiency in the workplace was born, and with it the first philosophies of management.

Widely credited as the first person to put management theories into writing, FW Taylor published a comprehensive thesis on the subject in 1911. Titled 'The Principles of Scientific Management' it proposed a system for obtaining the best output from blue-collar workers by applying scientific, rather than 'rule of thumb' techniques of management. He advocated the application of highly structured, experimentally based rules for workers, who he claimed were unable to decide for themselves how best to perform a task and who, without adequate direction, would try to get away with doing as little as possible. Although this is the crux of his theory, he also put forward novel opinions relating to many other aspects of the workplace, and summarised his work thus:

> "It is no single element, but rather the whole combination, that constitutes Scientific Management, which may be summarised as:
>
> Science, not rule of thumb
>
> Harmony, not discord
>
> Co-operation, not individualism
>
> Maximum output in place of restricted output
>
> The development of each man to his greatest efficiency and prosperity"[5]

Some of his opinions, notably on the ability and worth of workers, would in a modern day context be regarded as fundamentally flawed if not bigoted. However, this was a forward thinking philosophy, and many of its components form a basis for modern theories.

The next significant advance in manufacturing came at the start of the twentieth century following the invention of the motorcar. An insatiable demand created by an entirely new market provided Henry Ford, the founder of the Ford Motor Company, with the impetus to find ways of increasing output. His solution was the production line. By moving the product to the worker on a powered monorail, unnecessary movements were minimised and the workers could become more specialised.

The time taken for the first assembly job to use this new system dropped from 20 minutes to 5 minutes, and when later refined and extended to the whole production process of the Model T Ford, chassis assembly time dropped from 12 ½ hours to 93 minutes[6].

This innovation is one of the first signs of management theory improving the profitability of a company.

1.2.3 Industry in the War

Impetus for the next developments in process management came from the century's two World Wars. Recent technological advances including the automobile and aeroplane ensured that First and Second World Wars would be supported by an increasing array of weapons and mechanised transport. Consequently, the strategies and tactics of war, previously confined to the battlefield, spilled over into industry and production. Efficient use of raw materials and labour became vital to the support of front line forces, whilst continued technological advances were not only critical to maintaining or surpassing the balance of power, but provided the invention that finally brought the Second World War to an end.

Thus, in place of the conventional impetus for companies to compete and improve their methods, the wars (especially WWII) provided an even more urgent need to maximise quality, output and research, whilst making best use of limited resources. More by accident than design, this led to the development and use of many techniques now associated with concurrent engineering, most notably teamworking.

In this respect, the USA ranked amongst the most pioneering[7]. In 1941 a resolution was passed to allow the then president, Roosevelt to lease defence materials to those countries whose security America valued. Later that year, following Japan's attack on Pearl Harbor, they would join the war themselves. Still struggling to recover from the previous decade's depression, and lacking the dedicated military manufacturers existent in other countries, it was America's car industry who were given the task to develop and mass produce weapons. Companies such as Ford and Chrysler had already begun making use of cross discipline design teams before the war, and over the next four years they would regularly use such teams to ensure designs were easy to assemble and manufacture rapidly and cost effectively[8]. Products designed by such teams benefited from a deeper that usual consideration for ease of manufacture, and as highlighted later in Chapter 2, similar teamworking techniques are central to the concepts of concurrent engineering.

It is unsurprising however, that these techniques were evident elsewhere. In Britain, Japan and Germany, for instance, similar examples of a concurrent approach to design could be seen. The fact was that circumstance called for such considerations. What is more surprising is how, following the end of the Second World War, these methodologies were to a greater or lesser extent forgotten.

1.3 Changing Markets - The Last 50 Years

1.3.1 Post War Utility

Understandably, the period immediately after the Second World War was marked by a general feeling of relief. International market position and manufacturing output was predominantly dictated by the extent to which individual countries and regions had been targeted during the war. Europe had been severely hit, and took several years to rebuild their infrastructure and industrial sector. The Japanese economy was all but destroyed, and amongst the major players, only America had survived relatively unscathed. Without the incentives of war or competition, it could be understood why companies tended to revert to more traditional practices.

Initially, the design of manufactured goods adopted a highly utilitarian and purely functional style. The need to re-equip the population with basic equipment, whilst still working under the constraint of limited resources, was a large factor that contributed to the reduced emphasis on innovation and high quality design. However, these circumstances were not to last long. The 60's saw a new era of prosperity, and with the use of the transistor, a fresh boom in consumer goods. Once again demand outstripped supply, and hence quality was often forfeited.

1.3.2 Frankenstein's Monster

To find the next stage in the development of concurrent engineering, one must turn one's attention to Japan. Hit badly by the war, with two major industrial cities completely levelled, and economic output brought to a virtual standstill, Japan's miraculous recovery is not only a pointer to her innovative thinking and practices, but has been the driving reason, in order to remain competitive, for the development of similar techniques world-wide.

Data presented by Oppenheim[9], a commentator on Japanese success helps to put some perspective on the extent of their achievements: In 1952 their GNP was only 1/3 that of the UK. Over the following 25 years the GDP rose by 10.5% pa (twice that of anyone else's) to a point where in 1978 their GNP was more than double that of the UK and France combined. Today their economy is second only to America's, a fact that is even more marked when one considers that Japan has only 2.6% of the world's population and 0.1% of its land mass.

The reasons for this remarkable growth are numerous, complex and often contentious. Pre-war Japan was built around a sophisticated, hard working and well educated society, and had for decades prior to the war been the fastest growing economy in the world[10]. During the American occupation that followed the war, far reaching reforms to their constitution, laws, land ownership rights and education system were implemented, based on British and US best practices. By the time the Americans shipped out in 1952, Japan had the perfect foundation for growth and trading on the international stage. Furthermore, prevented through international treaty from maintaining a military force, and choosing to allocate less than half of what the west were spending to welfare, the new government was able to pour large investment into industrial regeneration.

All of this helps to account for Japan's rapid recovery, but it is their new approaches to design and manufacturing that explain why they have *remained* competitive, and often win in the battle for market supremacy.

Increasingly, markets were becoming far less affected by national barriers. Factors such as reduced costs of transportation and improving communication helped in promoting competition on a more global scale. The Japanese were quick to realise that any advantage over foreign competitors would translate into increased profitability. Two factors that contributed greatly to this advantage were the quality of their products and their market awareness.

1.3.2.1 'New Improved Quality'

Consultants Windermere Associates recently proposed a buying hierarchy to explain how a market reacts to the introduction and evolution of a new product:

> "...the product evolution model...describes as typical the following four phases: functionality, reliability, convenience and price. Initially, when no available product satisfies the functionality requirements of the market, the basis of competition, or the criteria by which product choice is made, tends to be product functionality. Once two or more products credibly satisfy the market's demand for functionality, however, customers can no longer base their choice of products on functionality, but tend to choose a product and vendor based on reliability..." and so on.[11]

In the developing electronics industry of the late 1950's and 60s this buying hierarchy can be applied to demonstrate how Japanese companies began to lose market share.

During a phase of rapid expansion, quality of goods was a secondary issue in a hungry market. However, in the face of competition from an increasing number of international players all providing similar goods, Japanese companies suffered as a result of their reputation for inferior reliability as compared to their rivals. A new approach would be needed to sustain their markets, and this would come from a fresh perspective on quality.

There is some debate as to who was most influential over Japan's quality revolution, and it is often not the originator, but his proponent to whom history bestows credit. Regardless of this however, two important factors to emerged from the 1950s and 60s were a redefinition of the meaning of quality, and a shift in the responsibility for its implementation.

Dr. Genichi Taguchi, whilst working for Japan's telecommunications company, NTT in the 1950's, proposed that quality should be incorporated into new products and processes from the outset of their development, rather than as an afterthought. His new definition of quality may not seem obvious at first, but holds within it part of the essence with which we appreciate the term today:

> "The author [Taguchi] defines the quality of an object as follows. Quality is the loss a product causes to society after being shipped, other than any losses caused by its intrinsic function."[12]

This loss to society is a broad concept that, with respect to a product alludes to any unnecessary or excessive use of resources in terms of time and money required to repair and maintain, pack and ship, dispose of or recycle, or use for the intended purpose during its life span. Essentially, the better the inherent quality of a product, the less it will cost the user, the supplier or society. Further to this, Taguchi's reasoning behind defining quality as a negative rather than positive characteristic was to make it more objectively quantifiable...

> "Some people hold that quality should be viewed as value. Value however is a subjective concept; everyone has his own idea of what constitutes value."[13]

He later extended this to include the time prior to shipment, stating a basic premise that a design must be robust enough to be made to good quality standards, despite inevitable variations in the manufacturing process. Here as we shall see, he is pointing towards a central tenet of concurrent engineering, that thought should be given during the design to all phases in a product's life, not just how well it fulfils its intended purpose.

Traditionally, quality had been regarded as a filter between manufacture and shipping to ensure that what went out of the door fell within acceptable standards. By comparison, this more conventional approach was far less efficient at achieving the desired effect, since the number of rejects was likely to be greater. Essentially the theory being applied was that of prevention as opposed to cure. Although similar thinking had preceded this, Taguchi's lasting contribution has been to develop techniques for predicting and analysing quality. The increasingly widespread appreciation and subsequent appropriation of his methodologies has yielded significant results, and at the time represented a shift in emphasis for companies.

> "...ITT trained 1200 engineers in Taguchi methods, and studied 2000 cases with the aid of Taguchi methodology. The results were savings of $35 million a year..."[14]

Around the same time W E Deming, an American working in Japan made an address to a selected audience of leading company executives in which he suggested that it was their responsibility to implement a change in attitude towards quality. Deming would subsequently become a major international proponent of new management techniques, and changing attitudes towards quality. In the 1960s he published a paper containing 14 points for management. Many of these points are not only relevant to the successful implementation of Concurrent Engineering, but may have been the seeds of its creation:

- "Cease *dependence* on *inspection* to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first place.
- Improve *constantly* and forever the system of production and service, to improve quality and productivity, and thus constantly decrease costs.
- Institute training on the job.
- *Break down barriers* between departments. People in research, design, sales and production must work as a team, to foresee problems of production and in use that may be encountered with the product or service.
- Remove barriers that rob the hourly worker of his right to pride of workmanship...
- Institute a vigorous program of education and self-improvement.
- Put *everybody* in the company to work to accomplish the transformation."[15]

Deming, together with the notable contributions of J M Juran and P B Crosby helped to ensure that by the end of the 1960s Japan had shaken off its reputation for poor quality, indeed...

> "Foreign competition began to threaten US companies in the 1970s. The quality of Japanese products such as cars and TVs began to surpass US-made goods"[16]

These concepts are now so ingrained into Japanese culture that statistical process control and quality circles form part of the school curriculum.[17]

1.3.2.2 Consumer Led Design

Riding on the back of US subsidies, Japan's drive to rebuild her post war industrial sector and catch up with the West, prompted companies to reassess other practices as well. Henry Ford is commonly quoted as saying that the customer could have any colour car, as long as it was black. This stance is explained by the fact that black paint was cheaper and faster drying, allowing greater production but at the expense of customer choice. This was a luxury which he could afford, but referring back to the buying hierarchy (ref page 7), with both functionality and reliability satisfied, Japanese companies made the astute observation that *convenience* could be the next weapon used as a means to gain the edge over their competitors.

By listening to the voice of their customers, manufacturers could find ways to make their products more attractive. Rather than designing a product based on a mixture of perceived need and specific in-house expertise, market research became a prerequisite of design. Once a clear understanding of what the customer wanted was gleaned, the product could be developed to meet that need - often requiring new manufacturing methods to achieve it.

However, no two customer's requirements are the same, and in an ideal world everyone would choose from an infinite number of variations. Patently, there is a limit to how far a company can bend to satisfy its customers.

The concept of modular design was one solution born from this discrepancy. By designing a finished product to be made up from interchangeable and/or optional components, the customer can be offered a greater choice, whilst the company avoids the expense of developing many discrete products. Modularity provided a two fold benefit. By applying the concept across a product range, the company can reduce the overall number of manufactured parts and increase the production volume of each part, thereby achieving further cost savings.

More recently, improvements in the procurement process and manufacturing techniques have allowed single product customisation to become a reality. The term Lean Production has been applied to these systems which "allow a greater variety of products to be made and new models to go into production faster." Further to this, "Agile manufacturing, the ability to thrive on constant change, adds additional flexibility to the lean system that forces it to change rapidly based on market conditions or customer requirements. In a truly agile system, a manufacturer can turn a profit on a production lot of one item!"[18]

A review of defence procurement in the USA highlighted how Japanese machine tool manufacturers have taken the concept of convenience further still, with the result of achieving market dominance over their American rivals:

> "The quality difference they noted was the extraordinary willingness of Japanese machine tool builders in particular to satisfy customer requests for unique capabilities, urgent delivery schedules, on-site maintenance, and proprietary acceptance tests."[19]

1.4 The Information Revolution

Early electrical goods such as the transistor radio were a major export from Japan, but there were soon to be major developments that it could further capitalise on. The rapid evolution of electronics over the past 20-30 years has had a significant effect on industry. The last part of this chapter explores how these changes have provided the final push towards the need for new working practices and the development of concurrent engineering.

1.4.1 The Birth of Computers

Although the term 'computer' as applied to a machine capable of handling numbers and calculations was coined by its inventor Charles Babbage in 1820, their widespread use in business and industry has only recently become commonplace. Their development has been wholly dependent on two of the twentieth century's most potent inventions, the transistor and its predecessor, the thermionic valve.

The Second World War witnessed the first use of computers, aiding Britain to decipher German coded messages. The aptly named Colossus filled several rooms, and required constant servicing to replace blown valves. After the end of the Second World War however, the invention of the transistor paved the way for far more reliable machines, and started the process of miniaturisation which has made possible the boom in consumer electronics we see today.

During the 1950's the first transistor based mainframe computers developed by Ferranti were used in business. Still behemoths by today's standards, these machines, were typically leased to a company by their makers (such as International Business Machines' IBM900 series). The next big jump in technology came in 1959 with the invention of the Integrated Circuit. The ability to fit thousands of transistors into the size of a postage stamp, and mass produce the chips allowed production of increasingly cheaper, smaller and more powerful machines.

1.4.2 Coming of Age

Once the trend of reducing size and increasing power was established, usage burgeoned at a similar rate. Although through the 60's and 70's computers were still the preserve of large companies, willing to invest still quite considerable sums of money in largely unproved technology, the past decade has witness the coming of age for the computer.

The new power of machines in the early eighties at last provided the opportunity for the final fundamental stage in their development. Apple computer's creation of the graphical user interface enabled anyone with little or no training to utilise their features. The widely copied, but largely unchanged operating system they developed replaced the previously incomprehensible text based black screens, and coupled with a mouse provided an attractive and far more intuitive way of interacting with the hardware.

Over the last 30 years, the processors inside desktop computers have developed from 4 bit versions carrying ~2000 transistors and using 1 Kb of RAM to the 64 bit Pentium group, carrying 7.5 million transistors and using 128 Mb of RAM. Price and processing power have now reached a point where computers are available and useful to companies of all sizes, whilst their widespread uptake and unquestioned utility has created a situation where it is less of an advantage to use them, as it is a disadvantage not to. As it will be shown, this turning point has had an enormous effect on the way businesses work, and is perhaps the most fundamental reason for the need, development and usage of many of the techniques and practices discussed in this paper.

1.4.3 New Products

Computers, and their peripherals are only one example of the application to which semiconductors have been put. Thanks to their incorporation into control systems, it is estimated that there are now five times as many chips in the world as there are people[20], and the electronics industry has ballooned over the past few decades to comprehensively dominate world manufacturing.

Products and their manufacturing processes have always been interdependent. Babbage's computer remained a paper fantasy until machines were developed capable of making it. Nowadays technology feeds its own growth by enabling faster and more complex development. Consequently, the rate of product introduction has grown exponentially. The inevitable consequence of this has been a steady drop in product lifespan. Whereas 30 years ago a new product could be expected to achieve worthwhile sales for 8-10 years, useful lifespan is nowadays measured in months (Figure 1.a).

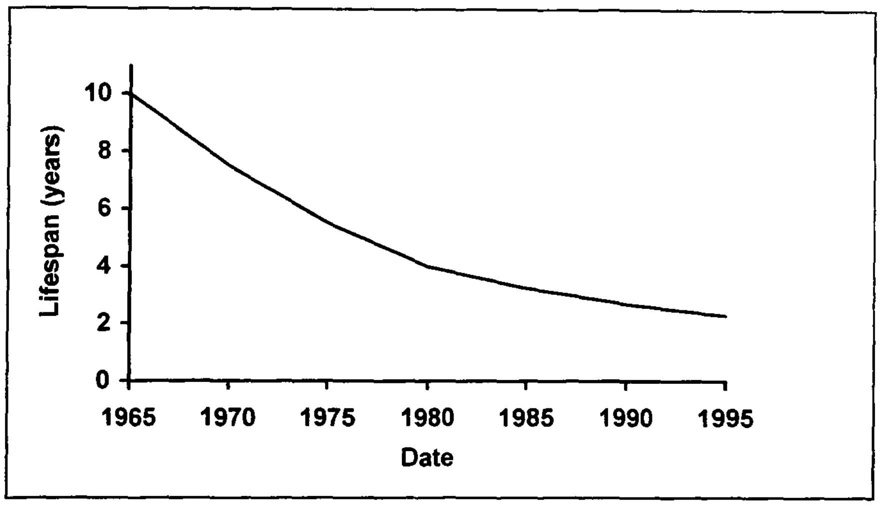


Figure 1.a Falling Product Lifespans[21]

Although this trend has been equally apparent in virtually all electro-technical product sales, its effect can be most graphically seen in the computer sector. Over the last decade the rate of new product introduction has risen three fold, to the point where a new machine purchased today will be obsolete within six months.

To the consumer, this trend is reaching frustrating proportions, and it may be that before long the market will begin to react, slowing the acceleration. However there is little evidence of this yet. Indeed, whether entirely knowingly or not, it is largely the consumer's heightening expectations and demand for better products that has fuelled such growth.

The effects of lifecycle compression to the companies designing these products are twofold. Firstly, the role of research and development has become far more important. Never has it been truer that a company standing still is in fact falling behind. Similarly, such development of new products must be carried out faster than before, in order to capitalise on a shrinking window of opportunity. (Refer also to Figure 2.c Effect of Delayed Market Entry on page 20)

1.4.4 New Practices

The rate of new product introductions on the high street has been matched by the development of a clutch of new products intended to aid product design itself. From their inception, computers have been used by scientists and engineers to perform complex or iterative calculations, providing faster and more accurate solutions to specific problems. As computing power has increased, these calculations have been increasingly embedded into a spectrum of software packages, enabling the user to interact more intuitively with the machine. So, for example: during the design of a support beam, instead of working out on paper an equation for the shear stress at a given point, and then typing this into the computer to get a discrete solution, the engineer can now simply draw the beam on screen, and with the touch of a button see graphically the distribution of stresses under a range of loading conditions and beam geometries. In a similar way, many other laborious tasks have been accelerated and simplified.

From the designer's perspective, computer based tools now exist to aid in almost all stages of the development process. Many of these will be discussed in the next chapter, as they can play a valuable and in many situations vital role in the concurrent engineering environment. For now though, the important point is that these tools in themselves have contributed to the faster development of more complex products. They form the final segment in the cycle of technological evolution and revolution which has stimulated the need for changes in working practices, and the emergence of concurrent engineering.

1.5 Summary

This chapter demonstrates how competition is the driving force behind change, and that developments in transportation and communication make competition fiercer now than ever before. Furthermore, new technology has led to reducing product lifespans, which combine to fuel an exponentially expanding technological revolution. These elements combined create an environment in which new working practices are a prerequisite to company survival. The origins of concurrent engineering can be seen in the examples of such new practices employed by proponents like Taylor and Taguchi.

The next chapter will show how concurrent engineering has developed from these ideas and has been used by medium to large organisations to gain competitive advantage. Linking these two chapters, it will become clear why similar techniques could be equally of use to smaller companies, all of whom face similar challenges and are competing for the same customers.

2 - The Philosophy of Concurrent Engineering

2.1 A New Strategy

As shown in the previous chapter, Japan not only recovered successfully after the Second World War, but by the late 1970's many of her companies had developed into world beating manufacturers. America and Europe found their products floundering in the face of stiff competition:

> "...in the 1980s...the flood of quality Japanese imports threatened U.S. manufacturers with virtual extinction. To the horror of U.S. industry, domestic customers in droves abandoned United States made automobiles, electronics, and other consumer goods in favour of the better quality Japanese imports."[22]

In order to lift themselves back on to level terms, the big American and European companies needed to re-think the way they worked.

The relative success of a company is defined at its most basic by how much and how quickly they generate revenue. The economics that describe how that revenue is generated can be simplified for the purposes of this discourse as follows:

$$\frac{\#Sales}{time} \times Profit\ Margin = \frac{Revenue}{time}$$

Consequently, to improve the fortunes of a company, an increased revenue can be created either by improving the rate of sales, or the profit margin associated with a product or products. The interdependence between sales and profit margin is quite complex, since lowering price (and therefore profit margin) may well lead to increased sales. For any product there is likely to be an optimum balance between price and sales that generates the highest revenue. However, though important, this decision was not a factor in the discrepancy between Far Eastern and Western company competitiveness - it can be assumed that Japanese companies were achieving higher sales *and* greater profit margins. Consequently, their advantage came from the efficiency of their business processes throughout the organisation, which contributed to higher sales and lower costs.

There are numerous ways in which these goals can be achieved, for instance by making a product more aesthetically pleasing, it would be hoped that more people would want to buy it. Alternatively, a novel method to cut back on manufacturing time (such as Ford's production line discussed in Section 1.2.2) will reduce the cost of the product resulting in a larger profit margin. Dealing with elements in isolation like this had in the past yielded significant reward (again, refer to the last chapter for examples), however the circumstances of the early 1980's asked for a more radical approach.

2.1.1 Concurrent Engineering Defined

At this time, DARPA - the American Defence Advanced Research Projects Agency - was commissioned to investigate ways of improving the quality and rate of product development. The report they produced defined a new, structured method of design, and coined the term Concurrent Engineering (CE) to describe it. Since then, CE has appeared in many guises (commonly also as simultaneous engineering) and been described in as many different ways, but in essence remains as their report first defined it, as...

> "...a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support."

The report continued...

> "This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept, through disposal, including quality, cost, schedule, and user requirements."[23]

The novelty of CE is the perspective from which it is intended to approach business processes. Traditionally, large organisations were highly departmentalised. Each department was managed and worked with a high degree of independence. This promoted a situation where improvements were implemented on an equally localised level. In contrast, the DARPA report suggested that by working *with* other departments, the design output could be optimised to the advantage of all downstream areas of the business. Hence by broadening the perspective of design, at the *earliest stage* in a product's evolution, this approach could be used to:

- *reduce costs*,
- *shorten development time* and consequently *increase sales*.

2.1.2 CE as a Tool for Cost Reduction

The CE methodology borrows a lot from Taguchi's theories in respect to defining the costs associated with a product. In calculating how much a product costs (in the sense of his 'loss to society', as discussed in Section 1.3.2.1) it becomes apparent that this wider perspective should always be considered, and its lifespan must be defined as broadly as possible. Everything that happens to a product from the moment it starts to be made, to the point where it ceases to exist must be included.

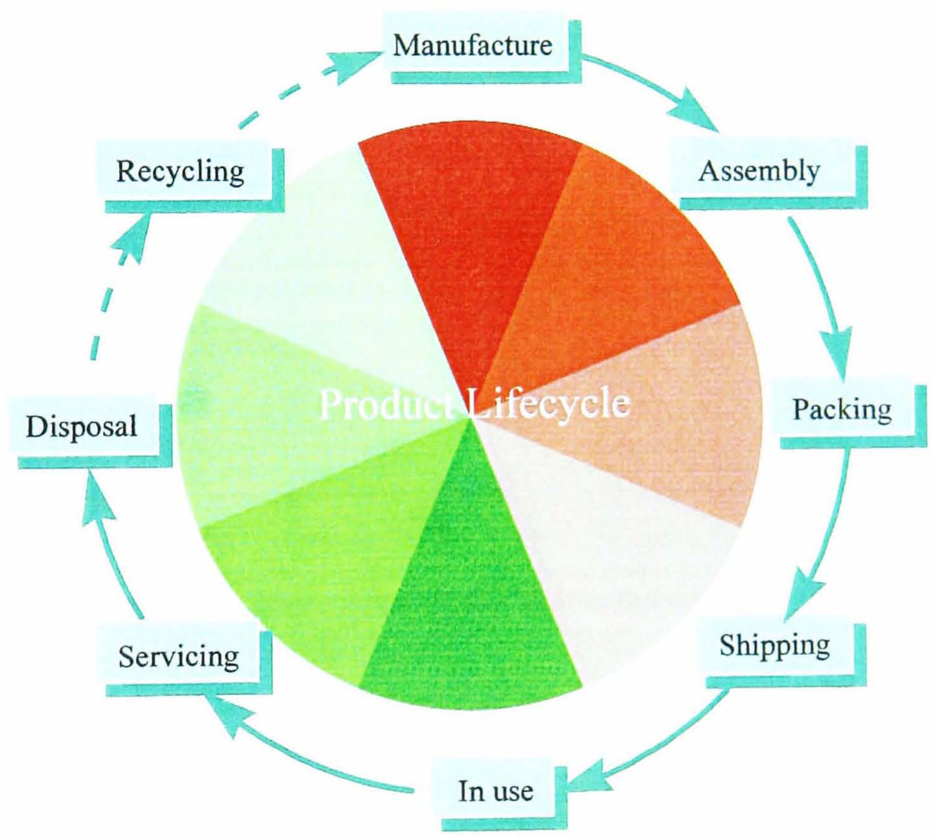


Figure 2.a Lifecycle Diagram - Elements of a Product's Life

As Figure 2.a illustrates, elements such as manufacturability, need for servicing and implications of disposal all affect the overall cost that a product will generate during its life.

Hence, by considering all these stages during the design of the product, CE aims to maximise the efficiency (or cost effectiveness) by which the product moves through the chain, whilst ensuring that it still meets the original requirements.

The influence of design decisions on overall cost is now widely recognised. In 1988, Dr Geoffrey Boothroyd published an article extolling the importance of estimating costs early in the design phase. In it, he quotes a report from the Ford motor company suggesting that despite design activity only accounting for ~5% of overall cost, 70% of the total product cost is influenced by design[24]. Gatenby and Foo[25] suggest an even greater proportion of 80-90% of total lifecycle cost being determined during the design phase. Whitney's[26] worrying conclusion is that designers make million dollar decisions every minute, without ever knowing it! Figure 2.b illustrates this point, and also shows that as development progresses, and more design decisions are made, the impact of those decisions diminishes, whilst overall development costs increase

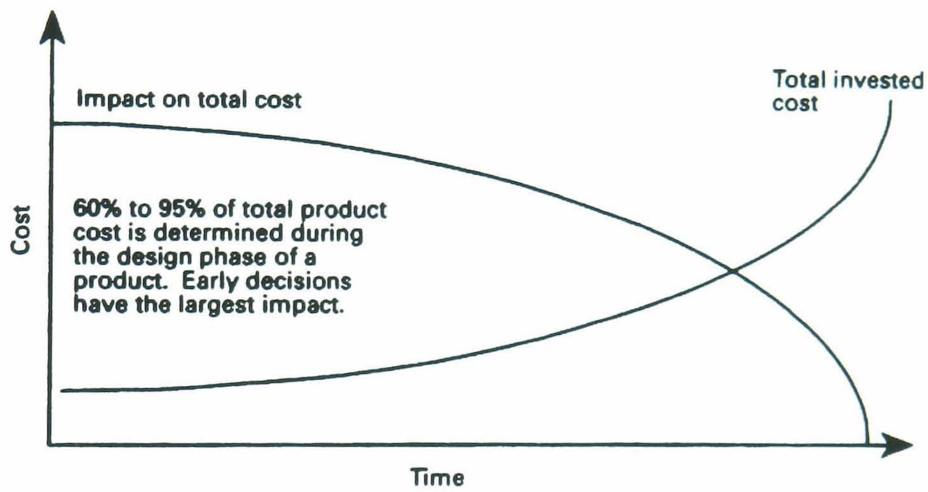


Figure 2.b Importance of Design on Lifecycle Cost [27]

Key areas for cost reduction within the company are manufacture and assembly, and this is born out by the overwhelming array of tools and techniques targeted toward this goal. Once again, figures suggesting the importance of good design with respect to these areas are common. Dixon & Duffey[28] state that a potential 40% of all quality problems can be traced to bad design, and Suh[29] claims that 70-80% of manufacturing productivity is determined during design. Here, the aim of a concurrent approach during development is to continually assess the design for ease of manufacture and assembly, and make changes as appropriate - without compromising function.

2.1.3 CE as a Tool for Increased Sales

Just as designing a product for ease of manufacture can help to reduce costs, concentrating attention on the customer can help to ensure that a product also fulfils their needs. Characteristics such as functionality, aesthetics, and ergonomics can all make a product more attractive to a potential customer, with the result of increasing the likelihood of a sale. However, there is another important way in which CE is intended to promote sales and that is by reducing overall development time. Just how important this is depends somewhat on the nature of the company's business, but some of its repercussions are equally beneficial to most organisations.

In the previous chapter it was shown how - especially in the electronics industry - useful product lifespans are reducing. This is defined as the length of time a product can remain in the market place before it becomes obsolete, at which point sales drop off dramatically, and the product needs to be retired, or replaced. It is clear that the sooner a product reaches the market place, the more prominence it will gain with respect to the competition, and the higher the total revenue it will achieve. This fact has been capitalised on by the Japanese, who according to data presented by Hartley and Mortimer[30] have an average development time >30% shorter than similar European companies. Research presented by Carter and Baker[31] defined a formula for the resultant loss of revenue, and illustrated the effect graphically (Figure 2.c)

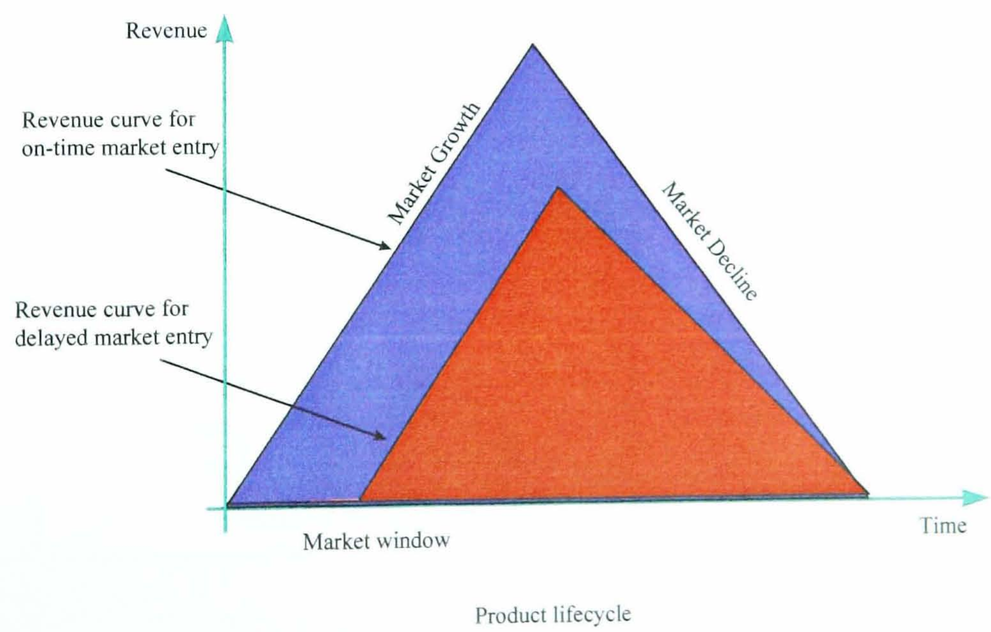


Figure 2.c Effect of Delayed Market Entry

The graph shows a revenue curve for two identical products. The integral of these curves (i.e. the shaded area under each one) equates to the total revenue the company will accrue during the lifespan of the product. The blue product is placed on the market at the optimum time. Sales increase over time to a maximum, before tailing off as the product becomes superseded by a better competitor. By contrast, the red product was released some time after its rival. It follows a similar pattern, but the market still dictates when sales will peak, and when the product becomes obsolete. Consequently, delayed market entry will cost the green company the difference in areas between blue and red in terms of lost revenue.

The way in which CE helps to reduce lead time is linked to the cross disciplinary approach it promotes. Conventional development follows a linear path, where each department's input is made sequentially. Not only does this approach introduce delays during transfer, but more significantly, problems can arise when a downstream department such as manufacturing finds difficulties with the design. The development is thus further hindered whilst a repeated iteration of the process is made to overcome the problem (see Figure 2.d). Additionally, there is evidence that the further a design has been progressed when such a problem is picked up, the more costly it is to correct, since financial commitment to a design increases at each stage. Indeed Siegal[32] claimed that the corrective cost of engineering change orders increases logarithmically as the orders are placed later in the product lifecycle. (This was illustrated earlier in Figure 2.b)

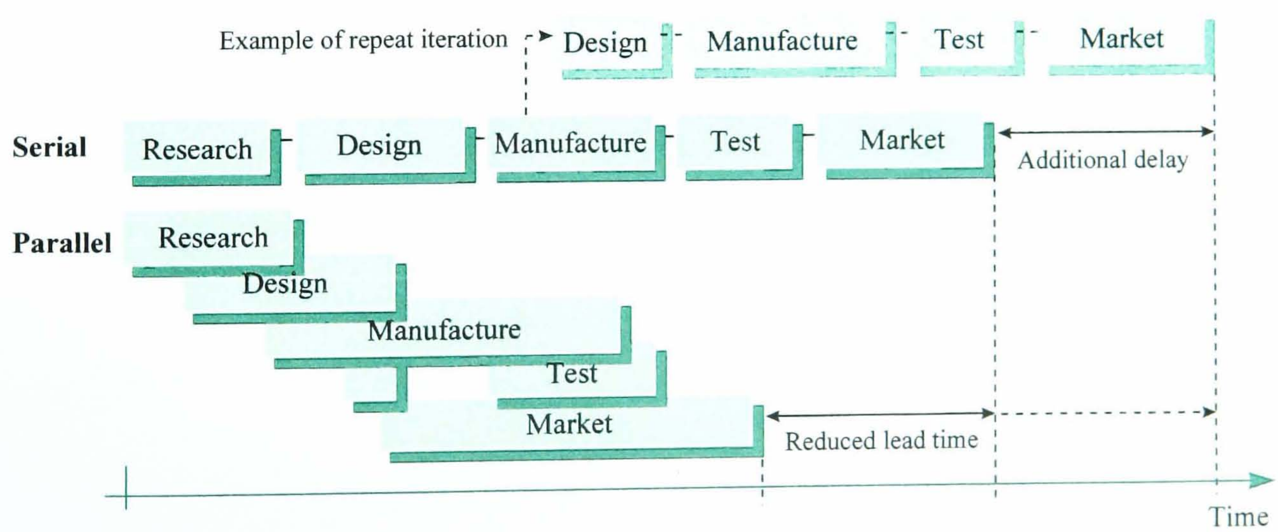


Figure 2.d Time Compression with CE

With CE, involvement of all departments during the design phase helps to ensure that once the design is sealed, and passed on to manufacturing, most potential problems will already have been ironed out. Furthermore, since downstream departments are aware of the progress of the design, they can make preparations to process it before it arrives at their point in the chain.

2.2 The Elements of Concurrent Engineering

How well a design performs during each stage of its lifecycle depends on its characteristics, both in isolation, and in relation to other parts and products. Figure 2.e shows some of the more important of these characteristics and which stage they have most bearing upon.

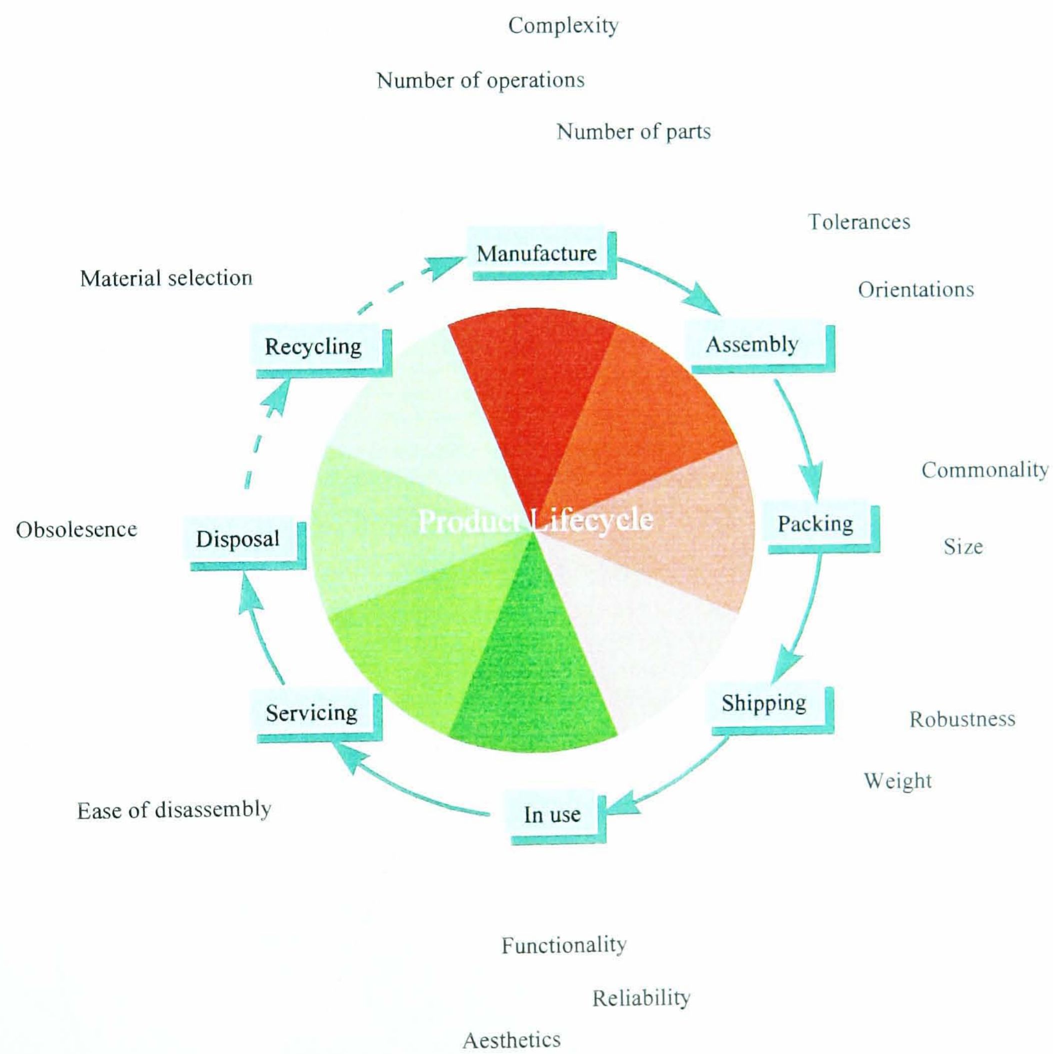


Figure 2.e Lifecycle Diagram Showing Characteristics

CE promotes the analysis of such characteristics, commonly through a structured use of subsidiary methodologies. Following the definition by DARPA quoted on page 17, concurrent engineering has come to be associated with a vast range of supporting tools and techniques, and pulls together many of the theories and practices introduced in Chapter 1 in order to help to achieve its basic principles of reduced development time, and improved product quality.

The more prominent of these tools are described in this section, together with examples of their implementation. The techniques discussed can be, and have been used in isolation without reference to concurrent engineering, an approach promoted by such departmentalisation as discussed earlier. They are presented here however, as aids to promote the ideals and the effective implementation of CE. Indeed some form an essential part of CE, and affect the entire development process. Others have a more specific sphere of influence, helping to optimise designs for a particular stage in the lifecycle. These latter techniques tend to fall under the general banner of Design For 'X' (DFX) as coined by Gatenby & Foo[33], 'X' being substituted with the stage in question, such as manufacture or assembly.
Figure 2.f expands upon the lifecycle diagram to show many of the tools discussed below, and illustrates how some are stage specific, while others are general in their influence.

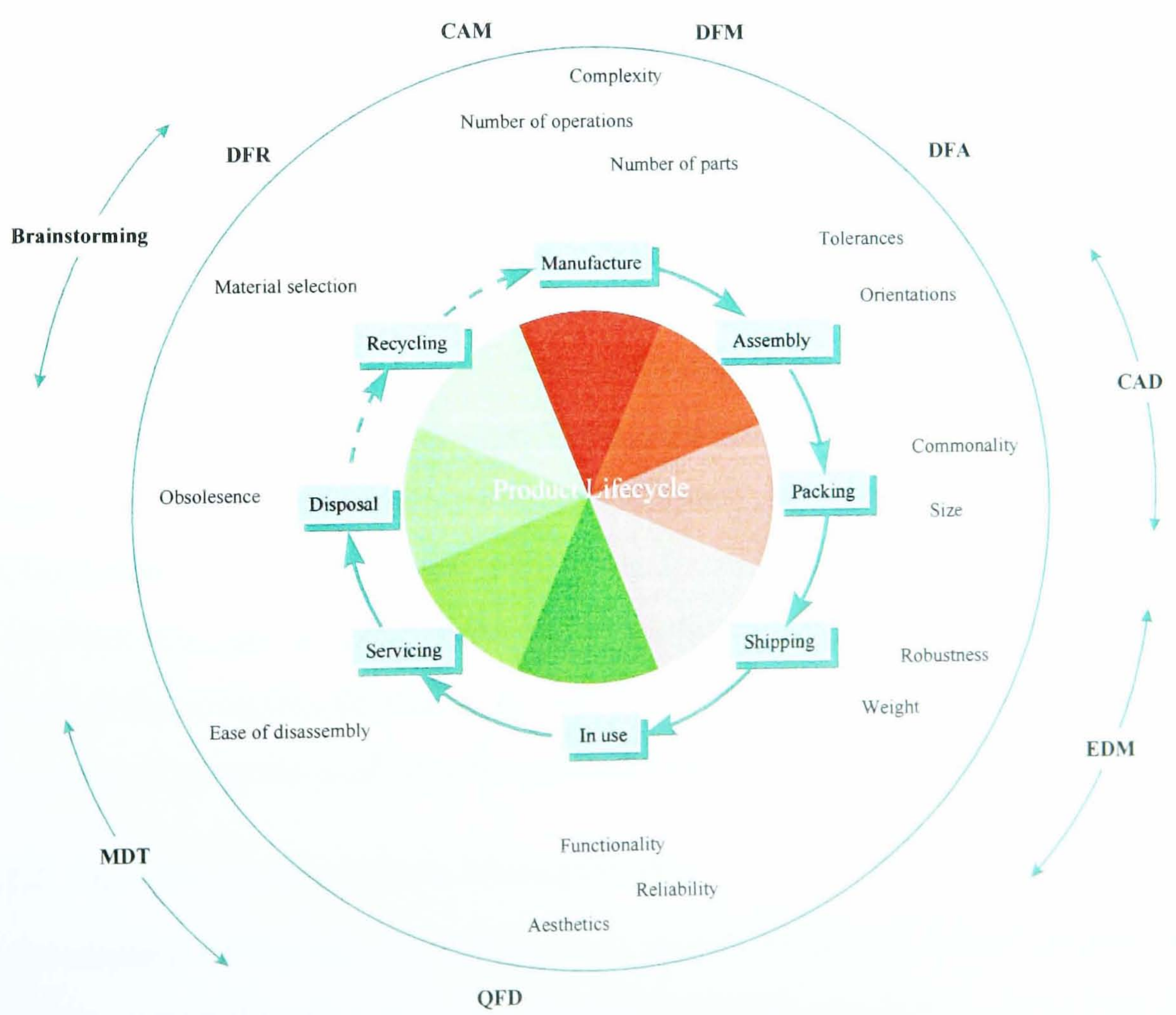


Figure 2.f Lifecycle Diagram Showing Characteristics and Tools

2.2.1 General Tools

2.2.1.1 Multi-Disciplinary Teamworking & Brainstorming

'A problem shared is a problem halved'. Although a cliché, the message of this proverb is fundamental to CE. Give a person a challenge, and they will arrive at a solution based on their personal knowledge. Give the same challenge to a team, and the solution will be different - reflecting the team's collective knowledge. Design is a series of such challenges, and the greater the knowledge and experience designers can draw upon the better.

Free flow of information is one of the key tools beneficial to designers. In a CE environment, teamworking has become the most common way of achieving this. (A survey conducted during 1993 in America '...overwhelmingly ranked [teamworking] as the No. 1 component of a CE program.'[34]) During development, the greater the number and more diverse the design options that are presented early on, the better the chances that the product will be designed right first time. The technique of ideas generation amongst a team of people is commonly referred to as brainstorming, and the unique perspective offered by each member rapidly creates a set of design solutions from which the best can be selected.

More often, these people are members of a multi-disciplinary team (MDT), where each of the lifecycle stages is represented by departmental specialists - hence each individual's contributions are coloured by a different perspective relating to their own field of expertise, and a product developed in such an environment should benefit from this. Use of such a team also helps to promote general communication throughout the company, providing the additional advantage that departments are more aware of progress, and can plan and react more quickly when the need arrives.

2.2.1.2 Documentation & Data Management

The assumption behind these intentions must be that one person cannot possess the knowledge required to give due consideration to all lifecycle factors - or at least that such consideration cannot be achieved fast enough. A further aid that can prove useful, given this situation, is detailed records of previous development projects. By documenting the decision making process, especially in a searchable medium such as on computer, future projects can avoid 're-inventing the wheel', and the experience of history is not forgotten. In larger environments, a central design database is also helpful in speeding up communication of progress between team members and departments. When implemented with the aid of IT, such systems of information logging are often grouped under the term EDM (electronic data management). An article published in 1994 claims that:

> '...the management of issue control and change process, plus searching for drawings and documents, can occupy between 25% and 45% of drawing office time...It is clear that the implementation of EDM is highly beneficial within the complex operation of large organisations.'[35]

Such benefits were reported in a DTI report in the same year, where a company of 750 employees implemented a fully paperless system of design and manufacturing management. They reduced the time to create bill of materials by 20-50%, and that taken to perform engineering changes by 60%[36].

2.2.1.3 Computer Aided Design & Manufacture

Section 1.4.4 introduced the topic of computers as tools in the design process. 'Computer Aided Design' (CAD) is a term which could today be used to describe any such application. However, it has instead come to be associated with the use of computers to draw, or model parts. Increasingly, these packages are then capable of simulating how such parts react to loading, temperature and other environmental conditions.

Computer Aided Design is invaluable in many respects. It can initially be used to help others visualise a component or product before it is prototyped, and later to automatically pass geometric data on to Computer Aided Manufacture (CAM) systems, bypassing the need for interpretation of drawings for programming of tooling paths. Also, in the past few years it has found another use, providing the data for Rapid Prototyping (RP) machines. These devices can create complex three dimensional parts from an epoxy or polymer based material, almost as easily as this page was printed in two dimensions. The dimensionally accurate prototype can then be used to create mock-ups for demonstration, and even short run mouldings to further test aspects of a design before committing to the expense of full scale production. Many companies have benefited from RP, notably in the electronics sector:

> 'Texas instruments developed RP technology to reduce product development time and cost and to get products to market more quickly. The company estimates that it has saved $4.5 million over the past four years by using stereolithography prototyping'[37]

2.2.2 Specific Tools

2.2.2.1 Design For Manufacture & Assembly

DFX describes a general principle of focusing design analysis on one specific lifecycle area, for instance DFM (Design For Manufacture) to ensure that a part can be manufactured with ease and consistency. This is often carried out with the use of software analysis tools. Assuming that the design is being developed with the help of CAD, it can be passed on to such a package, which will automatically assess such parameters as tooling requirements, tolerances and number of parts, and suggest ways of optimising the design. The originators of the first such commercial package were Boothroyd and Dewhurst, who, whilst working at Rhode Island University, registered the acronym DFMA (design for manufacture and assembly) as a trademark to describe their software. Dr Boothroyd was also responsible for the publication of an article in American Machinist (see reference 24) which describes the usage of such software to estimate production costs. In it he claims that 'Analysis tools known as Design for Assembly (DFA) are already available and have been applied with considerable success in many large organisations.' Similar products exist for the analysis of other stages in the lifecycle.

2.2.2.2 Customer Oriented Design & Quality Function Deployment

Returning to the equation for revenue on page 16, it is apparent that a perfectly tuned, optimally efficient company is of little use unless the products it makes sell, and for this reason satisfying the customer must be the first priority. An attractive product in terms of price, build, aesthetics, function or any other combination of assets, firstly gives marketing a direction, consequently boosts sales, and thirdly improves the reputation of the company or brand.

A new project should start with research into the market, and customer requirements, and the results of this should form the backbone of the whole development. CE aims to take this one stage further by involving the customer throughout the design process in the same way as other areas such as manufacturing. Ideally, the MDT should include, if not the customers themselves, then representatives who voice their genuine needs. In the absence of this, an objective analysis of genuine customer requirements can help to ensure that the most appropriate features are incorporated into a design.

Problems can often occur in the interpretation of such requirements. It is much easier to misinterpret the frequently non-technical statements of end users than those of say manufacturing, and this can be compounded when these requirements are passed on from user to sales rep to team member to the designer. One technique which can be used to overcome this during preliminary design stages is Quality Function Deployment (QFD). QFD, the meaning of which has probably been lost in its translation from Japanese is a system for ensuring that the most appropriate product is developed. QFD broadly follows the following process:

- Collect extensive market research from customers regarding own brand and competitor products.
- Comments are then condensed into a set of 'customer requirements'.
- These requirements are weighted to reflect their relative importance.
- The design team defines a set of 'design requirements' that address the customer requirements
- Each of the two sets of requirements can be rated against competitor products to identify weaknesses and strengths.
- Design and customer requirements are cross referenced in a translational matrix which reveals which design requirements are most important (see Figure 2.g).

- This process can be repeated to convert design requirements into part characteristics into process and manufacturing requirements.

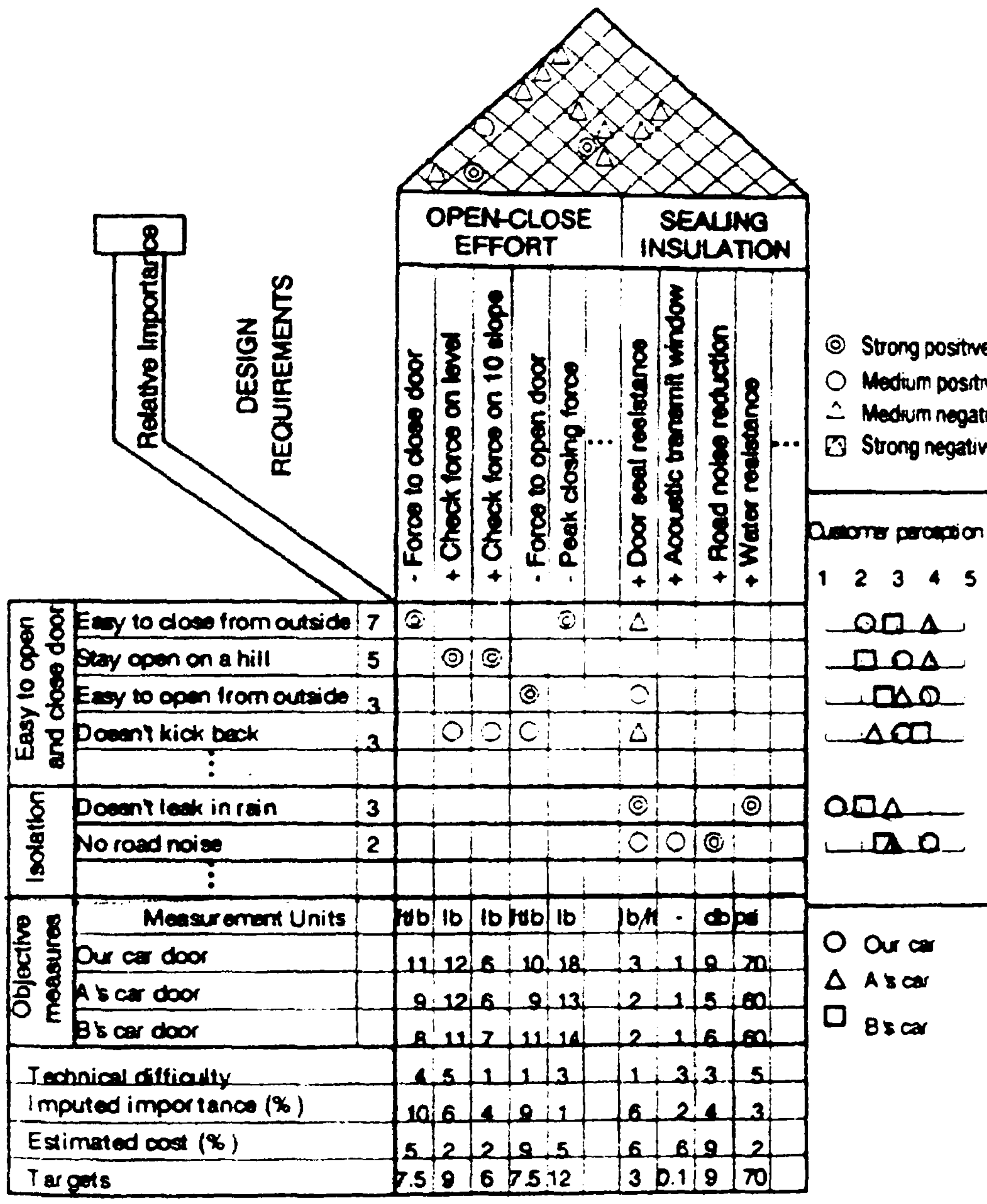


Figure 2.g QFD Example Matrix for car door[38]

QFD can be laborious, however many companies have found it to be a useful tool, indeed a 1986 survey of 135 large Japanese companies found 50% using QFD[39]. If used appropriately, its use can translate into considerable advantage, for instance Toyota claim a 40% reduction in the development cost for a new model and 50% reduction in development time following the introduction of QFD in 1977.[40]

2.3 Adoption & Adaption

2.3.1 Adoption

Following the publication of their report, DARPA undertook a campaign (DICE, the DARPA Initiative on CE) to encourage the widespread usage of CE in both the military and industry. Many big American companies were quick to adopt CE strategies, Chrysler, Ford and GM being amongst the first. Many of the big electronics companies in the States also started using CE to help them regain the market share that they were loosing to Japan. Digital claimed a 50% reduction in both time to market and product costs, coupled with a 100% increase in sales after only two years[41].

As information began to be published quantifying some of the benefits experienced, usage spread internationally. In Britain, companies such as Lucas, Rover and Rolls-Royce began implementing CE techniques in the late 1980s, once again with impressive results: Syan reports that "Rolls-Royce reduced their lead-time to develop a new aircraft engine by 30%"[42].

Evidence of successes such as these originates almost entirely from large organisations (>500 employees). This fact is unsurprising, since CE appears to have been originally geared towards overcoming the problems inherent with larger, more departmentalised companies. Often also geographically dispersed, meaningful communication in such companies can be difficult, and is not helped by the bureaucracy which separates functional and hierarchical levels.

2.3.2 Adaptation

This observation points towards an important aspect of CE implementation. No two companies are the same, and inevitably what works for one is unlikely to have the same effects for another. Almost all of the success stories quoted in this paper highlight one specific outcome from introduction of new techniques. This may be due to selective journalism, but it is proposed that there is a more basic reason:

Companies tend to undertake process re-engineering in response to one particular problem, for instance lead-times are too long, or reject rates too high. Although successful implementation of remedial action may have beneficial spin-offs, the most striking results will inevitably focus on that initial area. Hence the conclusion of this proposal is that different companies implement CE in different ways, and for different reasons.

Precisely which techniques to adopt is therefore a key question that should be comprehensively tackled long before the start of any CE program. A prescription from the doctor must be preceded by an examination and diagnosis, and the same is true for corporate strategy.

There are several analysis techniques in general use for targeting areas of poor efficiency with a view to strategic change. For instance, the SWOT analysis (Strengths, Weaknesses, Opportunities & Threats) highlights the best and worst characteristics of a company, and in addition incorporates external factors such as market openings, and competitors. Business Process Re-Engineering (BPRE) is more inwardly focused, and is useful for systematically rooting out problems.

The BPRE process usually begins by identifying the 'core competencies', those being four or five simple statements summing up the company's raison d'être. These can then be broken down into the processes that facilitate them, from which a picture can be built up of which processes need improvement. Armed with this information, relevant decisions can then be made regarding what targets to set, and how to achieve them. Figure 2.h describes such a course of action proposed by Booth[43] to take a company toward 'world class status'.

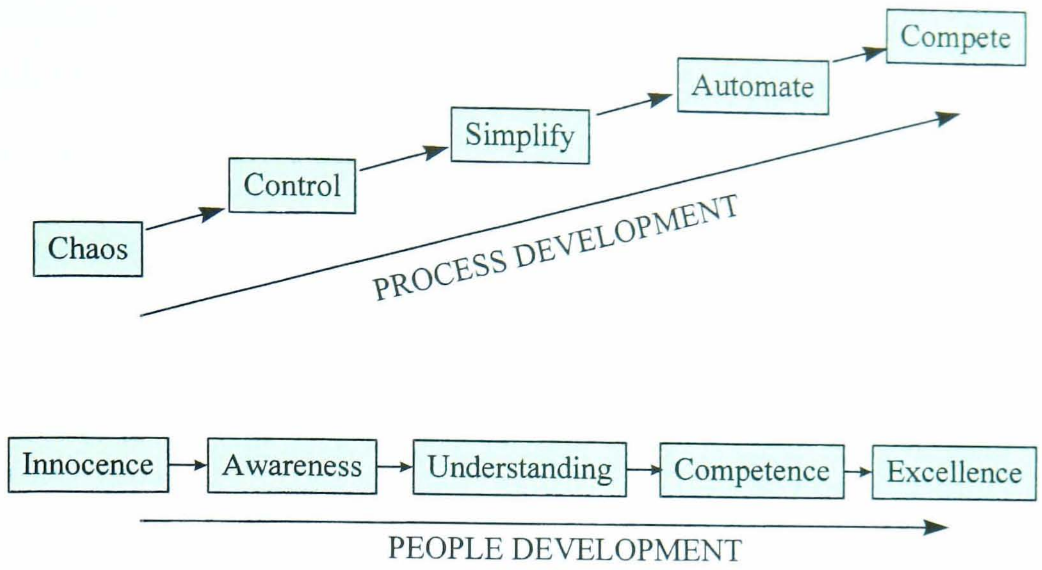


Figure 2.h Path to World Class Status[44]

Figure 2.h also shows the desire to develop the two dimensions of people and processes in tandem. So far in this discussion, the emphasis has been on the process aspects of CE. Experience has shown, however, that unless there is also careful consideration of the human dimension, the effectiveness of any implementation can be jeopardised. In the survey conducted by Lawson & Karandikar, 70% of respondents experienced a natural tendency not to change as a barrier to implementing CE. By comparison, the next biggest hindrance was a poorly defined CE process, and was encountered by 50%.[45]

A whole discipline has built up around the theories of change management, but two factors stand out: Firstly the importance of gaining the support from senior management, and secondly the need to involve the entire company in the process. Distinct parallels can be seen between this and the changes enforced at the start of the twentieth century during the mass production revolution. Following the introduction of assembly lines, resentment towards the management tended to grow amongst workers, who felt undervalued, and dictated to. Around this time, F W Taylor published his time & motion study 'Scientific Management', suggesting ways to improve the efficiency of the workforce. Working together in groups was something that Taylor, whilst discussing blue-collar workers, had actively discouraged, believing them to be less efficient than the separate sum of their parts. However, the 'Hawthorne Experiment' conducted during the '20s and '30s by Elton

Mayo yielded a quite different conclusion: that the best way to motivate was to involve, consult and give responsibility to the worker, and that productivity increased when workers were given the opportunity to form informal alliances[46].

This relationship can work effectively both ways. Just as the customer is the best person to consult regarding function, discussion with the people directly involved in manufacture and assembly can provide valuable feedback into ways of improving the design.

Resistance to new ideas, often an ingrained part of company culture, appears to be a common reason for unsuccessful adoption of CE. Research has shown that a significant proportion of companies that embark on a programme of implementation end up reverting to traditional practices. The Lawson and Karandikar survey found that only about 50% of the companies who had attempted to introduce CE claimed some improvement to cost, quality and time to market[47].

Virtually any CE textbook will suggest *why* a company should consider CE. Most texts then proceed to describe *how* CE can be used to tackle the 'whys' (e.g. how QFD can help to clarify customer requirements), and to present some of the common barriers, indeed the discussion in this chapter has so far followed this line of reasoning. However, it is proposed that to leave the analysis at this point tends to promote a rigid, and simplistic approach to CE implementation which does not take into consideration some important factors.

There has been little in the way of comprehensive research into CE application. The 'lack of interest in collecting metrics on investment and payback…' revealed in the survey by Lawson *et al.* may help to explain this. It is evident however, that there is a lot of data available, but most of it tends to present independent case studies, and focus on positive results. In the words of researchers Poolton and Barclay: '…there are few studies that have developed a framework for discriminating among firms based on their unique needs for the CE approach.'[48]

It is these '**unique needs**' that warrant further attention, especially when proposing to introduce CE techniques into the novel environment of small & medium enterprises. Beyond the most fundamental criteria flagged up during a BPRE type analysis, there are a whole host of other organisational characteristics which can impinge upon the design procedure, and may therefore need to be considered during the selection of CE tools.

Poolton & Barclay's research is based on the premise that '...firms have varying needs for CE and that the level of 'need' is governed primarily by the level of complexity of new products that are produced by firms.'[49] The findings of a survey they conducted led them to the conclusion that 'Those firms that had set about thoughtful planning for CE were more likely to be the larger firms among the sample and they were also most likely to develop the most complex products. In contrast, the smaller firms, and those most likely to develop the least complex products, were less likely to use dedicated teams and they rarely used techniques such as QFD.'[50]

They used these results to construct a framework for which product complexity was the sole variable in selection of CE tools. However, this overlooks one possible shortcoming: Removal of company size from the equation may once again oversimplify selection criteria. Although macro developments such as aircraft require substantial resources and are limited to large organisations, it does not follow that large organisations will inevitably develop complex products. The assumption that company size is reflected in product complexity can be seen to be untrue in many cases: Taking two local examples, The Thorn Lighting company has an annual turnover of £400 million, with offices in 25 countries, yet their products are in essence very simple, consisting of few parts and largely proven technology. By contrast, specialist sportscar manufacturers Morgan employ just 150 people, and has a turnover of £5-10 million.

The need to modify standard CE techniques for use in arenas beyond the corporate giants was also identified by Yan & Jiang (1999). They identified three disadvantages with the existing CE concept relating to the manpower resources and organisational structure of companies and the rigidity of MDTs. They claim that

'Those disadvantages greatly limit the application and popularisation of CE to the product development in enterprises, especially in small or medium sized firms.'[51] In order to overcome these drawbacks, they proposed an 'agile team' consisting of dynamically assigned members, not necessarily working in the same physical location, but co-ordinated through an EDM type computer network.

Although Yan & Jiang highlight two further organisational characteristics which effect CE, their solution is restricted to consideration of the teamworking element of CE. Furthermore, this solution still requires some considerable expenditure on IT equipment - a luxury which is beyond the financial resources of smaller companies, and may be considered by them as using a hammer to crack an egg.

It is clear then, that many factors are relevant to how any one company fashions their design process. So far the following organisational characteristics have been identified:

- Particular shortcomings of existing practices (as identified by BPRE)
- External market forces
- Available manpower resources
- Available financial resources
- Company size (number of employees)
- Organisational structure
- Product complexity

This thesis explores in depth how CE can be utilised in one specific small company. Chapter 6 returns to the discussion of which factors are seen to affect this implementation, but the underlying premise is that the size on the company will be the overriding criteria in CE adaptation. It may turn out to be the case that when *designing* a design procedure, the CE theory of lifecycle design should be employed! That is to say that a company should consider any relevant influencing characteristics before implementation to ensure that the product (that being 'the CE design procedure') is designed right first time.

2.4 Summary

This chapter has discussed the development of CE as a methodology to *improve product quality* and *reduce development time*. It has described its essential elements of *simultaneous* development of the *product & all related processes* through the use of a set of tools and practices. Examples have shown how its adoption in large companies has helped them to become more competitive and produce big improvements in sales and profit margins.

However, by examining existing research, it has become clear that there is little use of CE in small companies. This has been attributed to its origins in such large organisations whose structure and resources differ considerably.

Chapters 1 and 2 have highlighted that the fundamental reasons for the development of CE affect companies globally, regardless of their size, and that therefore it is not unreasonable to postulate that CE techniques could also be relevant to small companies. The remaining body of this thesis describes the research carried out by the author to test this hypothesis and examine what factors affect its use in this novel environment.

3 - The Company Profile

3.1 Background to the Company

3.1.1 Company History

Rimmer Brothers was the test company for the research presented in this thesis. The company was founded 75 years ago by brothers George and Ramsey as a diagnostic instrument manufacturer for the medical industry. Originally operating from a small London office, the company soon established a respected name for itself as suppliers of robust, high value medical products.

In more recent years a new sector developed allied to their speciality - that of laporoscopic or keyhole surgery. This field required highly engineered optical and mechanical devices, the development of which was unrealistic for such a company. Identifying the market opportunity, however, they formed a partnership with a large German company for sales, distribution and servicing of such equipment within the UK. This rapidly became the main source of turnover for Rimmer Brothers, and enabled them to expand their own in house product range with the purchase of a dedicated manufacturing unit in Ross-on-Wye in the early 70's.

The facilities at Ross comprised of about five numerically controlled milling machines and lathes, and in addition to producing the majority of their product component parts, they developed a subcontract client base to make full use of these resources.

Immediately prior to the start of this research, the company employed around 50 personnel, evenly divided between the administrative offices in London, and the plant in Ross. They still held a respected market position manufacturing precision surgical equipment, illumination accessories, and a range of electrical units including light sources and cautery devices. The sub-contract precision machining work was generating a significant revenue, but together these divisions still accounted for a fraction of their annual turnover of ~£6m, the rest coming from the agency. Figure

3.a below shows RB turnover, excluding agency sales, for the five year period leading up to the start of this research. It shows the four categories of sub-contract, fibre optics, cautery and lamps accounting for the largest proportion of sales.

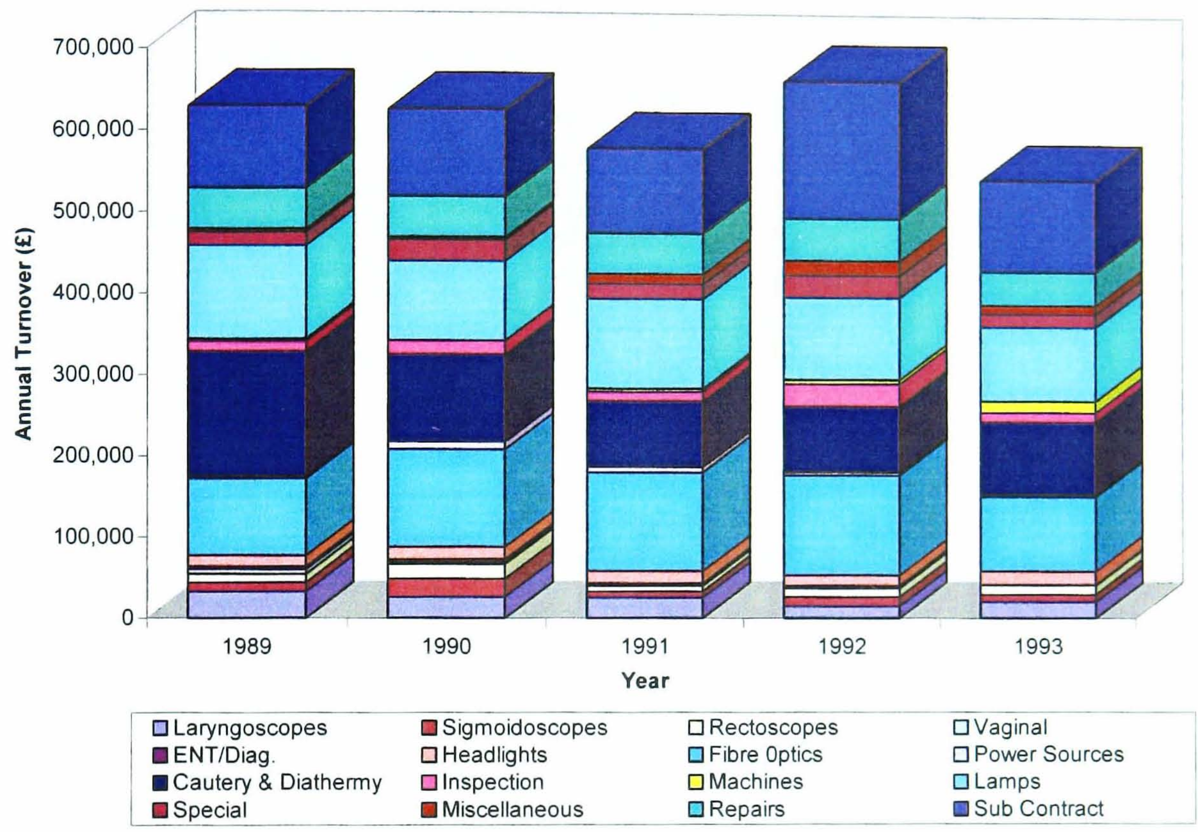


Figure 3.a Rimmer Brothers Product Sales

3.1.2 Organisational Structure

Essentially still a family business (with three Rimmers currently in the company), the work environment is fairly informal and friendly, as typified by many small companies. Communication between all levels at the Ross unit is very good, however, their geographical and functional separation from the London office provides some difficulties. Aside from a weekly visit by the Ross general manager to the headquarters, contact between the two offices is limited, and many long term employees have never even seen the other branch. There is a consequent lack of understanding of each others abilities, and some resentment apparent in London where jobs are threatened as manufacturing shifts to Ross.

The structure of the company is also complicated by its split location, and hierarchy is only loosely implied, but Figure 3.b illustrates the general chain of command

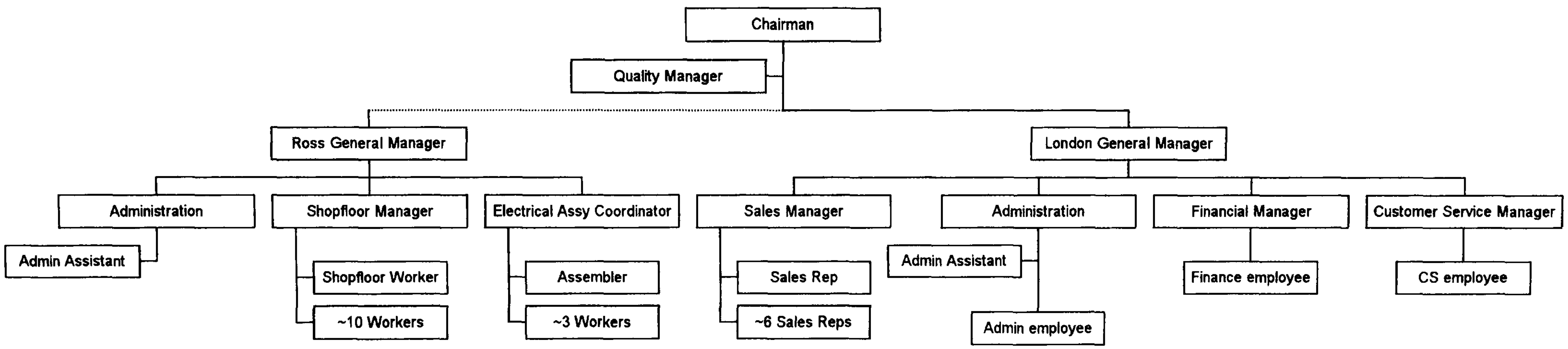


Figure 3.b Rimmer Brothers Hierarchy

3.2 A Need for Change

From the outset the company has endeavoured to stay at the forefront of its chosen specialities in illuminated and electro-cautery equipment. However, for some time there has been little investment in development, perhaps due to some complacency (not to mention restrictions imposed) with regard to the agency, but more probably simply because the market has traditionally remained quite static, with product lifespans tending to be measured in terms of decades as opposed to years, or even months as is more common in the retail electronics sector (Section 1.4.3).

The author has identified two key reasons for a change in this attitude which brought about the collaboration around which this research is based:

- Firstly, as mentioned above, a major change is taking place in the methods and equipment employed in surgery. The advent and proliferation of minimally invasive techniques, or keyhole surgery, has created a whole new market for supporting equipment such as endoscopes, remotely operated instruments and video monitoring systems. Although early research and development of such equipment tended to be conducted by more specialised and well funded companies, there is now a significant opportunity for others with a comparatively small investment to enter this lucrative sector.
- Secondly, and perhaps more importantly, Rimmer Brothers became aware that an over reliance on their agency agreement provided a uncontrollable and potentially dangerous situation, should the partnership ever come to an end.

So the decision was taken to increase the prominence of their own products. A glance across their ageing range immediately highlighted the need to update a number of products, before even considering new developments, in order to maintain competitiveness in an increasingly discerning and technological field.

Many designs had remained untouched for decades. Some were still using dated materials such as Bakelite, most came from a time when the word ergonomics hadn't been invented, and certainly they all could benefit to a greater or lesser extent from modern theories on lifecycle design to cut costs and improve quality.

Having identified a need, it was immediately apparent that the skills and resources required to undertake a programme of design and development were in short supply. Indeed, the company did not even have a product designer, relying for any new development on adhoc input from two of its senior managers. In summary, the following issues were identified as requiring attention for the programme of design and redevelopment to succeed:

- Insufficient manpower to devote to design tasks
- Slow product development times
- Labour intensive manufacturing processes for existing products
- Design process tending to create poorly conceived, expensive products

3.3 The Teaching Company Scheme

For this reason Rimmer Brothers approached Middlesex University with the proposal to set up a teaching company scheme. This would present the company with fresh talent, and expert knowledge in the field of process reengineering to help with strategic planning.

The Teaching Company Scheme (TCS) was set up in 1975 by the Department of Trade and Industry to help bridge the gap between academia and industry. Jointly funded by each of the three parties, the University employs a recent graduate and places them to work full time with the company. The placement 'associate' has access to the staff and resources at the college and working to a predefined programme, helps to transfer new knowledge to the company whilst working with them.

3.3.1 The Specific Programme

The first stage in the development of the teaching company programme was an objective analysis of the company's current position and needs as laid out above. This was conducted by the management committee, a group consisting of representatives from each of the parties involved - in this case, three from Middlesex, two from the company, and one from the DTI.

In the light of this information, it was noted that concurrent engineering had been used by other companies to tackle similar issues (i.e. to reduce development time and improve product design output). The hypothesis was then proposed that although there was little precedent for its use in small companies, *a sympathetically tailored implementation of concurrent engineering in Rimmer Brothers could be applied with success*.

Once a strategy was agreed, a specific set of goals were defined, together with timescales, and a statement of the resources (both in terms of man hours and budget) required to achieve them. These goals were as follows:

1. Conduct marketing survey to identify market segments and products with high earnings potential.
2. Introduce a suitable CE based design process to enable fast and effective product development.
3. Proceed to design and develop products as identified in stage 1 at the proposed rate of two per year.
4. Make changes to the design process as appropriate in the light of experience.

Finally, a company mission statement for the scheme was created:

"Increase market share by 20% by conducting product development for the range of illuminated surgical instruments and associated equipment. Bring on stream innovative new products and manufacturing methods."

This statement relates to the objectives by summarising that the company sought to improve its design facility by giving greater consideration to quality, and reducing lead times, therefore allowing it to efficiently and rapidly develop a number of products, identified by suitable market research. This approach, together with a closer consideration of manufacturing efficiency was predicted to enable the desired increase in market share.

3.4 Summary

This chapter has provided an introduction to the medical device manufacturer: Rimmer Brothers, and described their general structure, characterised as a small company with a flat hierarchy. It proceeded to cite their product design problems, and a market driven need for change as reasons for approaching the TCS. The problems facing the company, including a slow and ill-considered design process, were seen to be the same as those that concurrent engineering seeks to remedy.

In terms of size, hierarchy, culture and turnover Rimmer Brothers has been shown to be quite different from the traditional environment in which CE is applied. Furthermore, inevitably the perspective and objectives of each party in such a collaboration is different. However, as the following chapter will demonstrate, the intention of the scheme was that the university's research into the application of concurrent engineering in small companies could help the company to achieve its aims of reduced development time and increased product quality.

4 - Implementation

As discussed in the last chapter, Rimmer Brothers entered into the teaching company scheme having highlighted some areas where the management could see a need for improvement. Concurrent Engineering was suggested as a means to help the company improve working practices and together with the associates employed on the scheme, to achieve their long term goals of improved sales and market share. As discussed in Chapter 2, CE has been used elsewhere to achieve similar results. It was the intention that by applying its principles to Rimmer Brothers, greater collaboration between departments during design would promote these long term objectives.

Having broadly identified the company's problems of a dilapidated product range in need of rapid improvement, the TCS team members established two aims for the scheme:

- Improve product quality - i.e. increase the efficiency with which products move through their lifecycle by making them more cost effective to manufacture and assemble, whilst maintaining functional suitability, and increasing their desirability to the customer.
- Reduce lead times - i.e. maximise market opportunity and lifespan by decreasing the amount of time taken to develop new products.

Once the first associate was in place, it would then be their task to develop a strategy for achieving these aims by suitable application of concurrent engineering principles.

Before instigating changes within the company, however, a more thorough understanding of their particular shortcomings was needed. This would help in two ways: firstly to ensure that the concurrent engineering scheme implemented was tailored to target these problem areas, and secondly so that as the scheme progressed, a comparison could be made with practices beforehand to help quantify the benefits (or otherwise) achieved.

4.1 Analysing Problems

4.1.1 The Design Process

A browse through the company's brochure revealed a product range that was suffering from long term neglect. Those products on offer had evidently survived the test of time in the marketplace by natural selection more than by design. Although they were solidly built, reliable, and performed their function adequately - or even admirably in some cases - a closer look at their characteristics often revealed dated materials, expensive manufacturing processes, and inefficient resource usage.

These problems were traced back to poor design practices, and a lack of resources available for development. More specifically, the company's most obvious shortcoming was the lack of a dedicated design engineer. They were therefore forced to rely upon adhoc input from managers for design work. This situation created a number of problems: Time input for any one project was erratic, and on the whole, inadequate. This in turn meant that the number of design alternatives considered early in the project was limited. The more that such limits are imposed, the less it is possible to extend considerations to include lifecycle elements beyond pure functionality, and consequently the final design suffered from inadequate initial research, high manufacturing costs, and poor aesthetics.

Furthermore, the work that was conducted was rarely documented sufficiently, if at all, which points toward another fundamental problem area: The lack of an enforced design procedure, with associated documentation, made control and traceability difficult. With no agreed specification, validation and verification of the final design was almost impossible, and budgeting for resources proved to be a haphazard process. This would also hinder redevelopment as this research will later show.

Finally, old working practices were also hindering the development process. The use of computers within the company was minimal, and confined to administration and finance. Without CAD, drawing generation was laborious, whilst updates and changes to existing drawings required starting from scratch. Once again this could only be serving as a disincentive to maintaining paperwork.

On the subject of working practices, it is important to note at this point to what extent the company operated a serial development process, as contrasted in Chapter 2 with the parallel nature of CE. Whilst they certainly did not suffer to the extent of some larger companies with respect to departmentalisation, there was still a tendency to design in isolation, giving little consideration to downstream processes beyond the experiential knowledge of the designer. This was certainly evident in some product designs, and in the length and cost of development. A deeper discussion of this factor will be saved until the conclusions of this thesis.

4.1.2 Company Culture

A full picture of the interactions between personnel and an understanding of their individual agendas is of course very difficult to piece together from the perspective of an external assessment. Yet, as suggested in Chapter 2, company culture can be a significant factor in both the efficiency of a company and the success of implementing change.

Over the course of the teaching company programme, an increasing appreciation of these factors has helped the concurrent engineering scheme to evolve to work more effectively within Rimmer Brothers. However, some important, and more obvious characteristics were noted at the start of the programme:

As stated in Chapter 3, the company is split into two premises, the London office primarily handling sales, finance and administration, and the Ross factory mainly manufacturing. Design work was on the whole also based in London, although some projects were undertaken in Ross. The geographical separation could be seen to significantly affect communication, and with substantially only one point of communication between the two sites, the manufacturing unit was run almost autonomously. Certainly this caused some disincentive to involve all departments during product development, with manufacturing more often excluded.

The two units were, and still are quite different internally. The London building is a rabbit warren of offices spanning six storeys, and its hierarchical structure reflects this, with 4-5 levels from packers to chairman. Communication through these levels is adequate, if little more. The Ross branch, by contrast is flatter both in architecture and hierarchy. The organisational structure extends to 2-3 levels, and the flow of information between them is good.

It was unclear at the outset as to how the company would react to change. Certainly the instigators of the TC programme were open to experiment with new ideas, but how the rest of the company, including the senior levels, would react remained to be seen.

4.2 Developing a Strategy

4.2.1 A Note on the Teaching Company Programme

At the outset of the TCS programme, the intention was to employ two associates, each for 2 years and overlapping by 12 months. The first associate would set up a design department in London, and use concurrent engineering to help develop a number of new and existing products, whilst the second associate would be based in Ross-on-Wye, and concentrate on improving manufacturing efficiency. However, the first associate made the decision to leave the scheme twelve months early when the second associate was brought on board. It was decided at that point, following an assessment of the achievements to date, to continue with the first associate's remit of CE implementation and product development. The changeover also provided the opportunity to appraise progress from a fresh perspective, and so presentation of the work carried out in this and the next chapter will inevitably fall into two sections: before and after this hand-over.

4.2.2 First Phase Implementation

The first associate began work in 1994. Based in London, his first task was to conduct a market survey of Rimmer Brother's existing products in order to prioritise product development. Working with sales and marketing, he identified the biggest selling products, and by cross referencing this with a breakdown of the devices most in need of redesign, decided on the order with which they should be tackled.

Following on from this, he initiated the implementation of concurrent engineering, and using this, began development of two products. The two most significant contributions he made were to set up a product development team, and to procure computer aided design software. The team consisted of himself and senior managers intended to represent marketing, finance, manufacturing and electronics design. Meetings were scheduled to happen on a monthly basis, and would include a presentation of project progress, followed by discussion over how to proceed.

The CAD package purchased was AutoCAD release 12. An industry standard, this software provided the designer with the ability to create fairly complex 3D wireframe design models which could then be rendered with surface textures to produce adequately realistic representations of design concepts. The files created could, if required, subsequently be transferred to a third party for the purposes of manufacture or prototyping.

4.2.3 Second Phase Implementation

4.2.3.1 Re-assessment

Although the second associate was intended to continue the work started on implementing CE during product design, it was decided that he should be based at the Ross premises. This decision was based on the need to interact more freely with manufacturing during the design process. As stated, the changeover also provided a valuable opportunity to evaluate the success of CE so far, and to make certain changes. The next chapter will demonstrate in detail how CE was used during both phases for product development, meanwhile this section is concerned with why and how CE was developed during the scheme.

Besides the re-location of the design department, the author soon found it necessary to make a number of other changes to the way CE was being used. Although some progress had been made, after one year the management had not seen any tangible results from the use of CE. By scrapping certain elements and modifying others, it was hoped that, with the benefit of the experiences from the first twelve months CE could be more effectively integrated and adopted by the company to produce genuinely positive results.

One such tool whose adoption was ditched following this appraisal was QFD. Intended to increase the prominence, and understand better the voice of the customer, the first associate had begun researching the use of QFD. There is much evidence of its worth in this area (see Section 2.2.2.2) when applied in large companies, however QFD can be laborious, and needs a commitment to poll a statistically significant number of people to work effectively. It was therefore decided that with the limited resources of this small company, and the urgent need to increase the rate of product introduction, time could be more effectively spent in other areas, whilst the needs of the customer would still be represented by the added inclusion of sales representatives in the product development team.

4.2.3.2 The Fluid Design Team

Perceived as the most important element of this CE scheme, the constitution and effectiveness of the product development team received close scrutiny following the changeover. At this point, although the design team had certainly represented a positive step towards increasing lifecycle considerations earlier in the development process, it had not worked as effectively as had been hoped. Firstly, the team members had been chosen as much on the basis of their seniority as on their ability to represent different departmental areas. This led to a situation where meetings became more of a progress report than a constructive design session. Secondly, meetings were rigidly enforced in terms of attendees and frequency. It was clear that this was both difficult and undesirable to maintain. Design decisions were being delayed until such meetings, and some of those present were wholly superfluous to requirements. The conclusion was to change the concept of the team from a rigid number of members, meeting at fixed intervals to a much more informal structure.

The new team consisted of two layers, an inner core of four members who would participate in all arranged meetings, and a peripheral ring of others whose particular expertise could be called upon as and when needed (Figure 4.a shows this arrangement, with members denoted by their initials). The main intention in doing this was to enable more frequent and relevant meetings. Thus meetings early on, during the initiation stage of a project, would involve members representing sales and marketing, ensuring that the specification was in accord with the customer and the company's vision. Later, as the design moved on to concept development, more frequent contributions from manufacturing could be made, without having the delay of organising a full CE meeting.

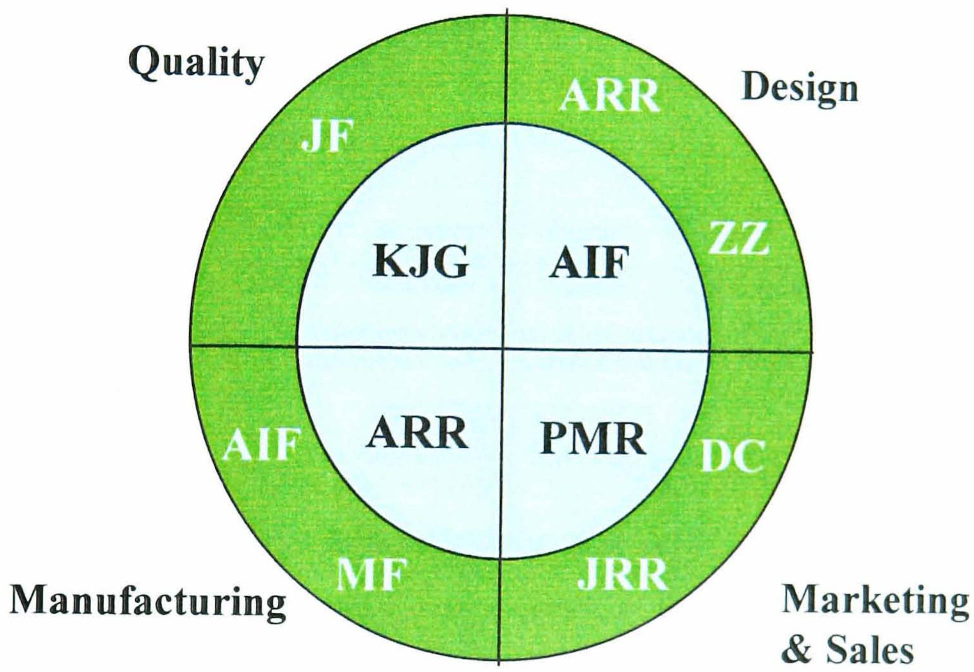


Figure 4.a Two Tier CE Team

Furthermore, it was decided to include a more diverse spectrum of members. Initially the official team consisted of only management personnel. It was felt that this did not help to propagate the ideals of the scheme to lower levels within the company, and failed to capitalise on their knowledge and perspective. Hence the new team would draw upon the experience of machine operators and assemblers as well.

4.2.3.3 Quality Approach

Whilst the team was becoming more informal, another aspect of the scheme would receive a much more formal treatment. To date, despite middle management's commitment to experiment with concurrent engineering, there was concern that without the driving force of the TCS and its associates, the company would be reticent to maintain and develop its usage. Hence, in order to promote long term acceptance it was decided that the company operating procedure (COP) relating to design would be re-written to reflect the ideals of CE (the complete procedure can be found in Appendix B). A sanction to allow several weeks work towards this goal provided an encouraging demonstration of the middle management's commitment and long term vision.

The COP is a hefty document, originally written many years ago, which defines in detail exactly what process must be followed, and what accompanying documentation must be created (and filed) to achieve an end result. It covers all aspects of the day to day running of the company, and its usage forms the basis for compliance with the standards for quality assurance. Continued compliance is ensured through regular assessments by a third party, and approval grants the company ISO9001 approval. Thus by incorporating CE practices into this fundamental document their continued usage should be ensured.

A further advantage of defining in detail how the design procedure works is that responsibilities are allocated, and the process becomes more tangible. One other important issue that was flagged up during the process refinement was that the design department was perceived by other team members to be responsible for ***all*** aspects of the development. Being a department of one, this was clearly impossible to achieve. In addition to the COP, a flowchart of the design procedure was created, further clarifying departmental input (Figure 4.b & Appendix A) with the intention of delegating certain tasks to those with relevant expertise.
This chart, together with the COP, was written to comply with BS EN ISO9001 (incorporating the British standard for design procedures) and has gained the approval of the quality assurance body to confirm this fact.

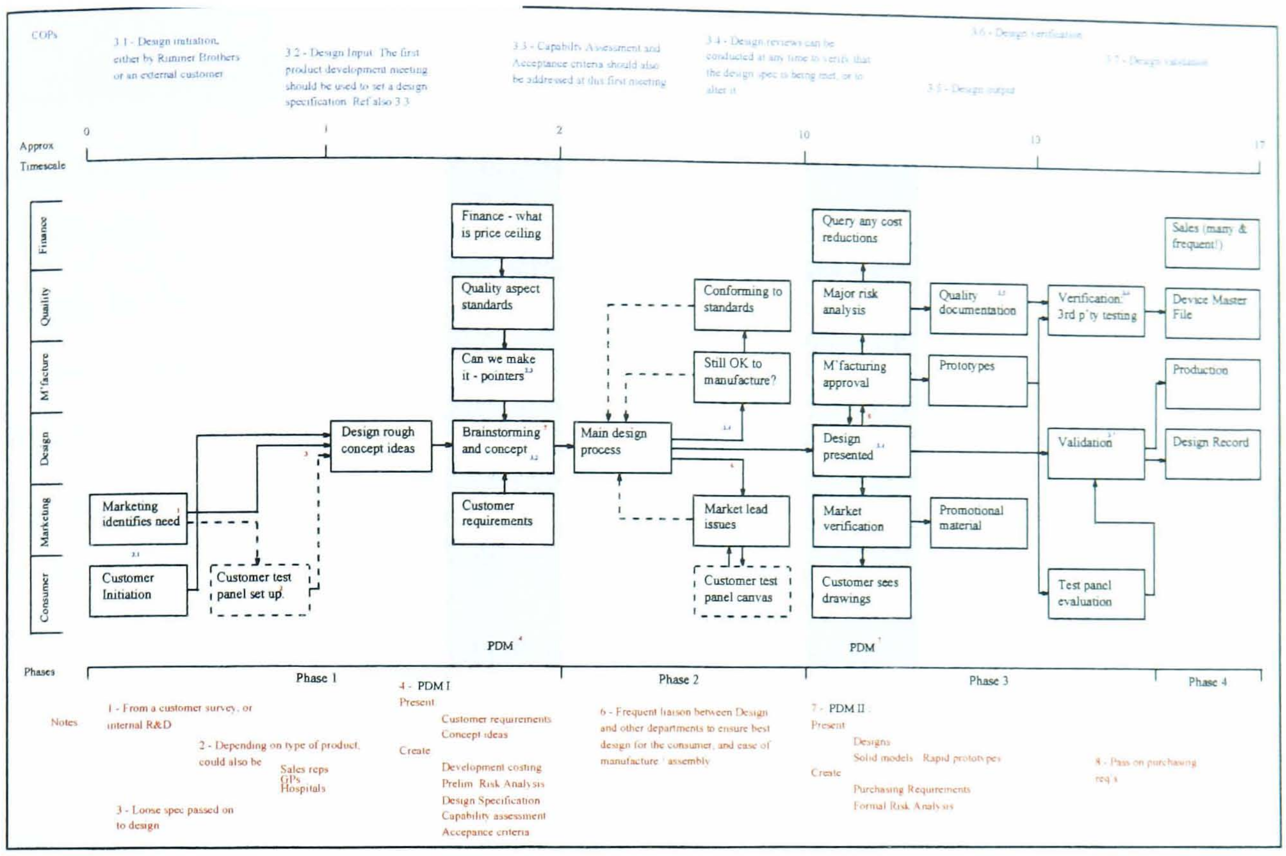


Figure 4.b Design Flowchart (enlarged in Appendix A)

4.3 Summary

This chapter has described the specific problems facing Rimmer Brothers design function: lack of a dedicated design engineer; erratic and inadequate time devoted to design; lack of background research prior to design; poor consideration of product lifecycle elements early in the design process; and insufficient documentation. The tools and techniques implemented in order to tackle these problems, such as teamworking, CAD and documentation procedures have been described. The rationale for the selection, exclusion or modification of CE tools has been discussed with reference to the controlling factors of company culture and limits on resources. A fuller analysis of these issues has been left for the discussion in Chapter 6, where the experiences gained from applying CE during the development of products, found in the interim chapter, can be included.

5 - Product Developments

The test for any concurrent engineering scheme is to see how product development is affected by it. This chapter describes a number of projects that were carried out during the three year teaching company scheme, and which made use, to varying extents, of the CE procedures discussed in Chapter 4. Broadly speaking, these projects fall into two categories - those initiated by the first associate during year one, and those carried out by the author following this period. The original choice of products to develop followed a period of market research and sales analysis. However, priorities inevitably changed during the scheme and, as discussed below some projects were not carried through to completion. Although they cannot offer a full analysis of the effectiveness of the procedures in terms of overall timescales and results, they do demonstrate the use of certain elements, and together with the other projects provide a complete picture of the techniques and tools used.

5.1 Hand-over Projects

As stated in Chapter 4, this TCS programme has been conducted in two stages, with work undertaken by two associates. Inevitably this thesis concentrates on the work carried out by the author during the second, and largest of the two phases. At the point of changeover, there were three design projects in progress. The change in personnel and location provided an opportunity to re-assess the importance of these projects, and to shelve those that were decided to be less urgent in favour of others. Two of these projects are discussed below. Although only one of them was carried through to completion during the second phase, both show a degree of relevance to this discourse.

5.1.1 Light Duty Cautery Handle

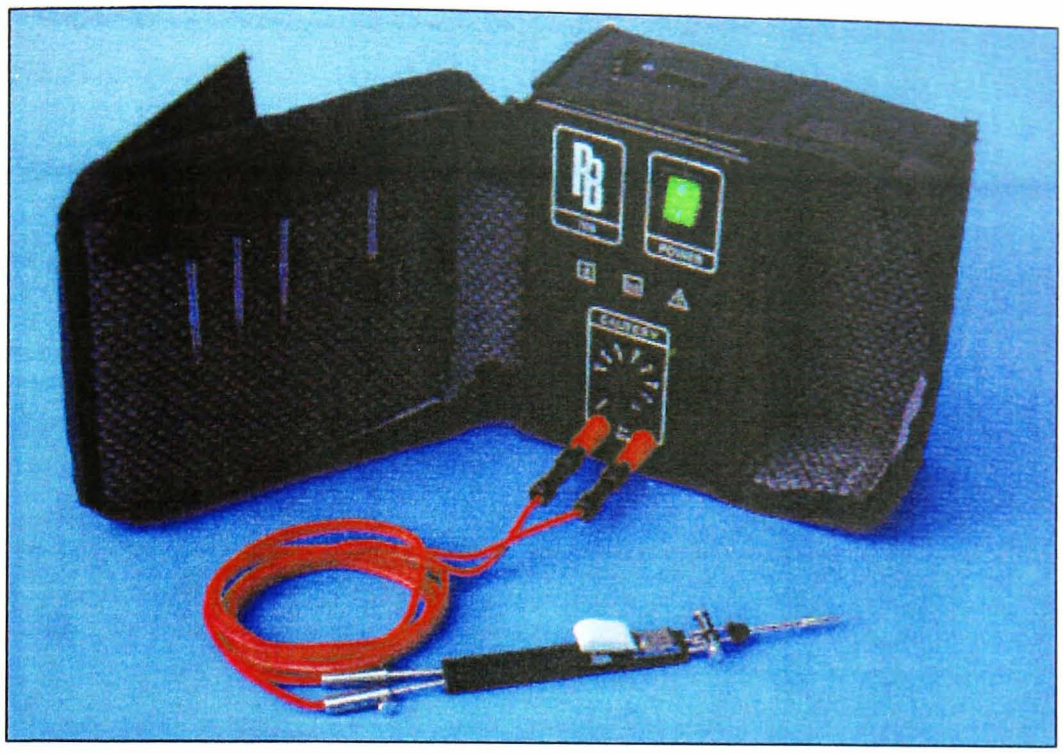


Figure 5.a Old Cautery Set

5.1.1.1 Preamble

Alongside Rimmer Brothers' speciality in illuminated instruments, they have since their inception provided a range of equipment to GPs, hospitals and the military for the cauterisation of tissue. Working something like a sophisticated soldering iron, an electric current is used to rapidly heat a thin strand of wire (the burner) to the point where its delicate application can burn tissue. Its primary use is in the sealing of blood vessels by coagulation, although it also has use for the removal of skin defects.

The equipment range consisted of two sets, characterised by differing power outputs. The design of most of the components in each set was, however distinctly dated. Ergonomically poor, expensive to produce and utilising outdated materials such as Bakelite, these products were the first to be targeted by the company for re-design.

As the larger selling product, the light duty cautery set was tackled first. Each set consists of a mains powered transformer unit which supplies power directly to the burners via a cable and handle (Figure 5.a). Although the transformer units would be the subject of a later update, it was the handles that were most in need of replacement. The existing 'Mark Hovell' handle supplied in the light duty sets was designed many years ago, and originally used ebonite, a material long since superseded by synthetic polymers. Consisting of thirteen separate parts plus fastenings (Figure 5.b), its manufacture was highly labour intensive and costly, and the end-product cumbersome and awkward to use.

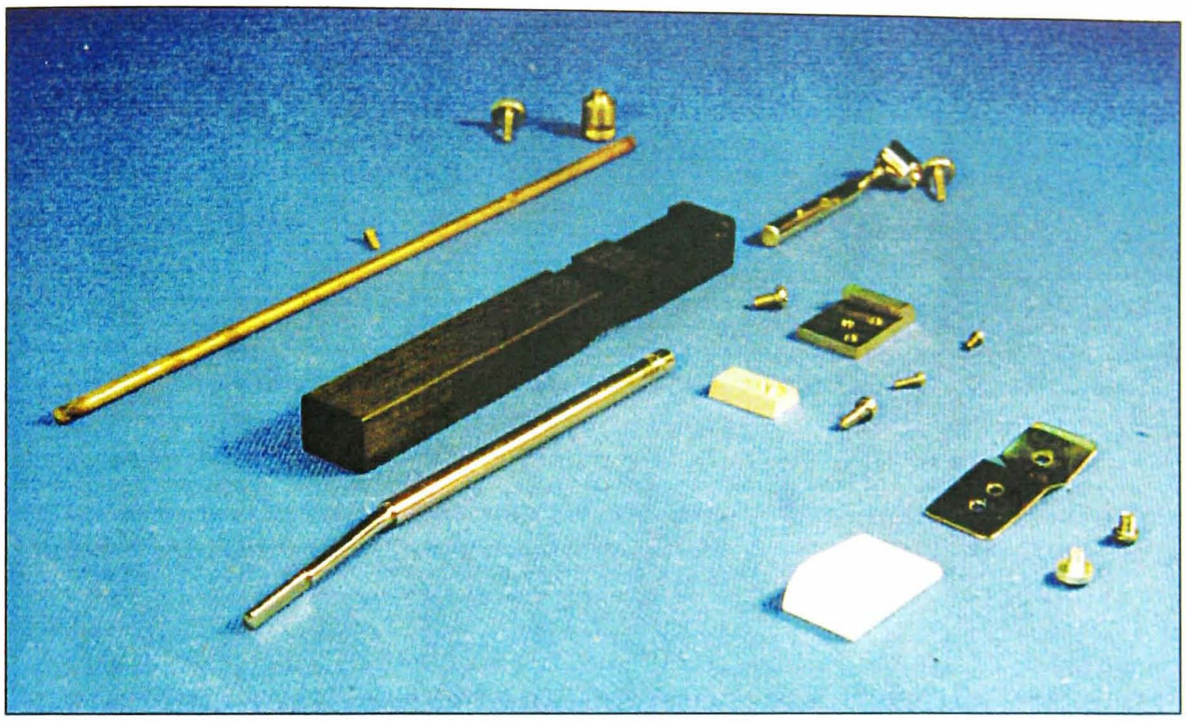


Figure 5.b Hovell Handle Parts

The design remit was to tackle these areas, whilst maintaining the high quality apparent in the original. One other significant characteristic to preserve was that of autoclavability. This sterilisation process requires that the device withstand cyclical high temperatures, humidity and pressure, placing restrictions on materials selection.

5.1.1.2 Project Status at Handover

Development of a new cautery handle was apparently well advanced when the author took over the project, and it was expected that the product would reach the market in a matter of weeks. The previous associate had used the early CE team to help develop a product that successfully fulfilled many of the original requirements, and the design had already moved from prototype to pre-production.

In brief, the design of the new push button handle was based on two injection moulded halves to reduce machining time, and incorporated a microswitch actuator which significantly cut-down on the number of parts. The profile (Figure 5.c) had been agreed by the team, having used 3D modelling techniques to visualise a number of alternatives, and proved to be far more comfortable to hold than the old handle.

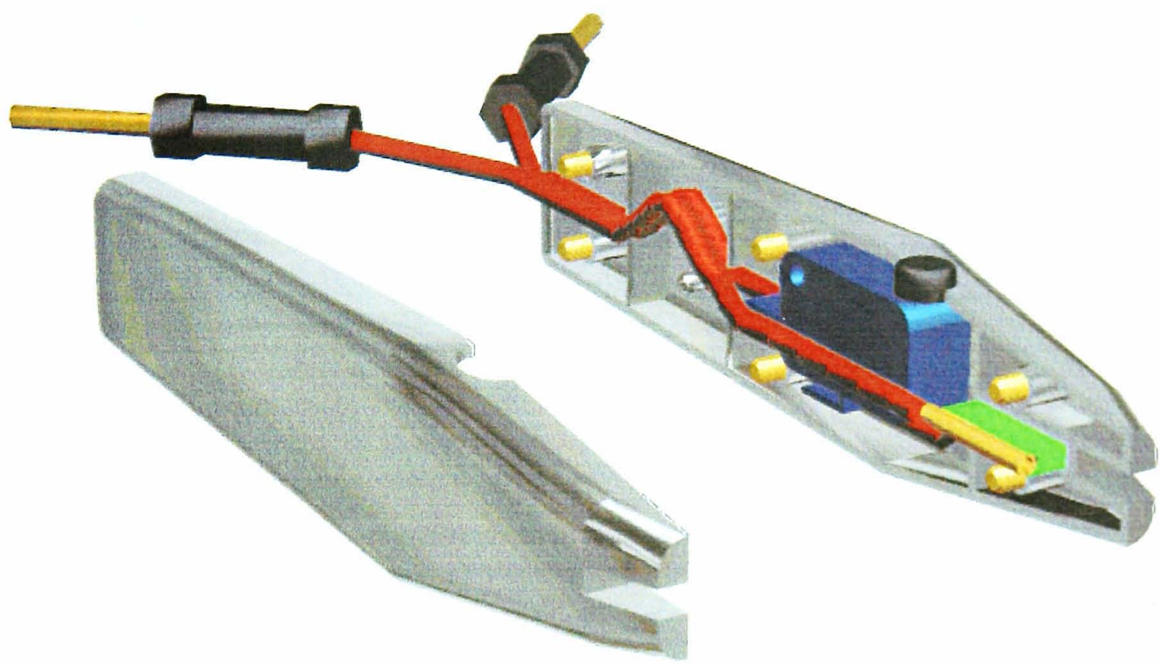


Figure 5.c 1st Generation New Handle

Unfortunately, one fundamental point had been overlooked during development, and this would set the project back considerably. Having found no record of material testing in the design record, a series of autoclave tests were quickly arranged. The results were dramatic. Although the plastic used, Nylon 6, had a melting temperature considerably higher than those experienced during the sterilisation process, the handle was returned from testing after only five cycles completely destroyed (Figure 5.d). It was immediately apparent that the failure mode was environmental stress cracking caused by the cyclical hydrolisation of the Nylon.

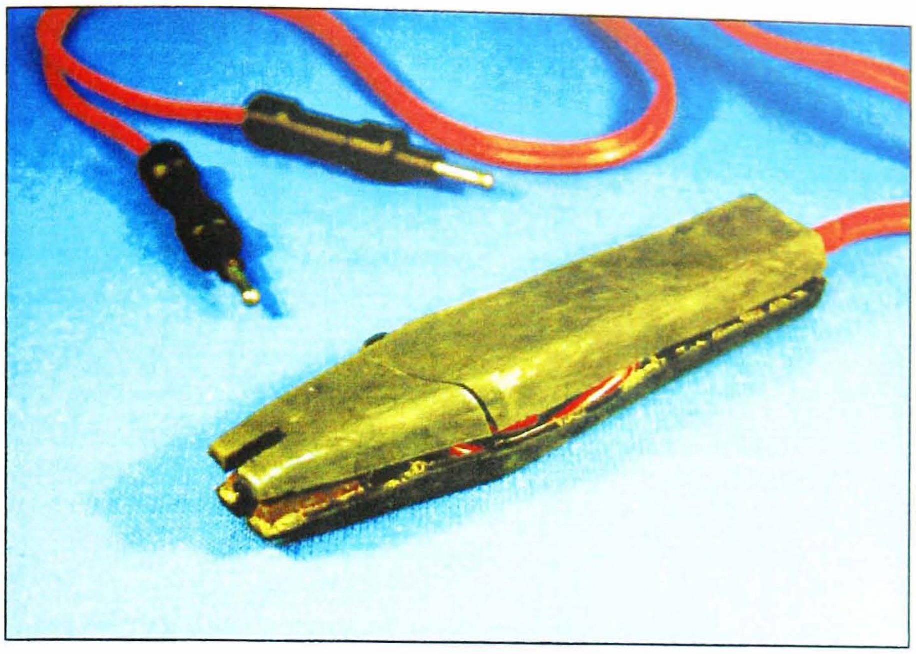


Figure 5.d Autoclaved Handle

5.1.1.3 Handle Re-development

Investigation into an alternative material that would withstand autoclave conditions was carried out. A number of alternatives were available - including Polycarbonate, Polypropylene and Polyamide, but the choice was limited by manufacturing capabilities. Rimmer Brothers are essentially metal machinists, and the size of the nylon moulding was already stretching the abilities of their small injection moulding machine.

At the same time, given the enforced opportunity to re-assess the design as it stood, a meeting of team members concluded that some significant improvements could still be made. The points highlighted follow:

- The weight of the handle was not enough to feel substantial, and counteract the pull of the attached cable. With the 'tail wagging the dog' the handle rarely stayed where it was put.
- Further to this issue, the plastic provided no grip to help the handle stay either in the hand, or on a surface.
- Ingress of water was undesirable, and could constitute a safety risk.
- The join line between mould halves was unsightly, and frequently disjointed.
- Assembly of the handle was awkward and time consuming.

- Obtaining a consistent surface finish on the mouldings was impossible, and would lead to a significant rejection rate.
- Original cables were no longer available

The conclusion of these discussions was to write off the design work already carried out, and design a new moulding using rubber instead of plastic. A local manufacturer with whom Rimmer Brothers had worked in the past was willing to work with the team in advising development and undertaking final production of the handle. In this way it could be ensured that the appropriate material was selected, and the tooling designed correctly to the limitations of rubber moulding.

CAD and 3D modelling was invaluable during this development, without which communication of ideas to the moulding company would have been much harder, and the relatively complex tooling could not have been designed so quickly, if at all. The final design is shown in Figure 5.e.

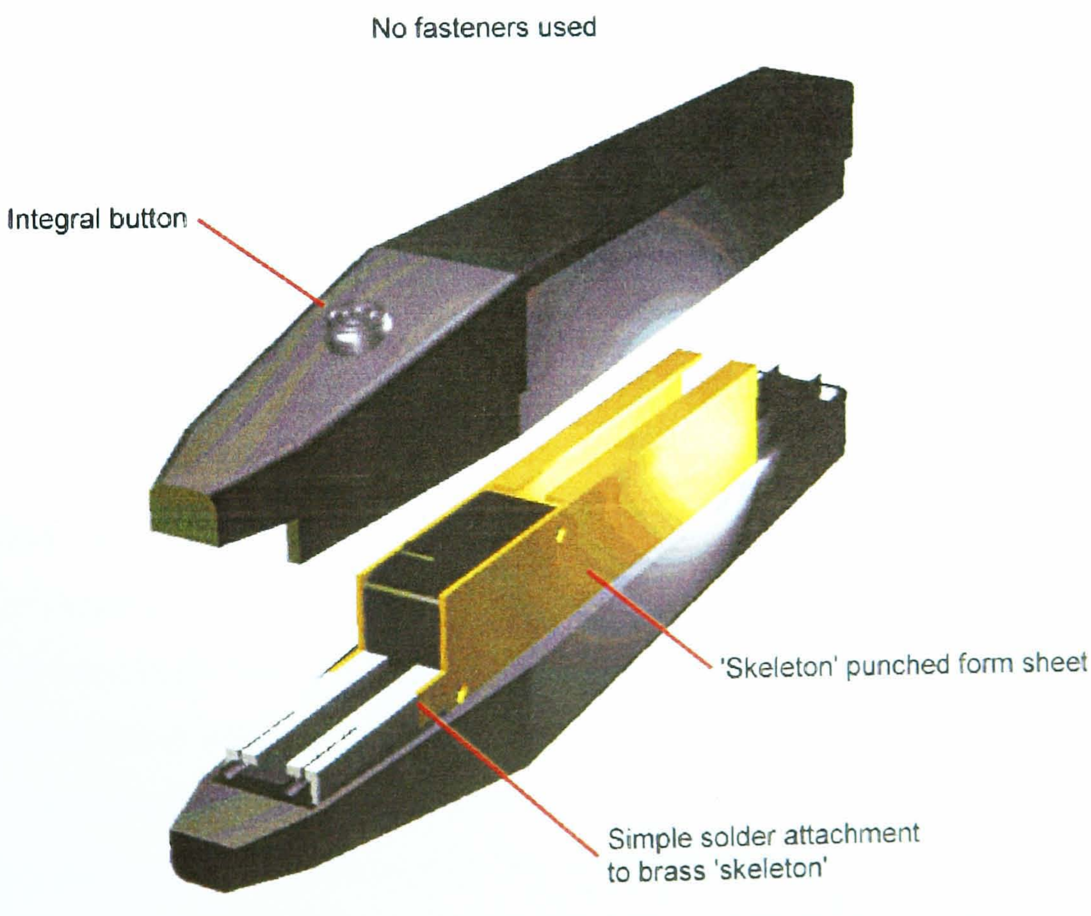


Figure 5.e 2nd Generation New Handle

Compression rubber moulding allowed weight to be increased by removing only the material necessary to fit internal components, whilst the choice of EPDM rubber gave the handle far better grip - encouraging it to stay where it was put! The join line has been developed into a feature by rotating it through 90 degrees, and finally a combination of silicone sealant and a heat curing epoxy firmly bonds the assembly and prevents the ingress of moisture.

Field trials were conducted following the first pre-production run to assess the feedback of users. This information was useful in final selection of the adhesive, and would be relevant to aid future developments, including that of the heavy duty version. From the perspective of the CE process, it also helped to confirm that communication channels with the customer had worked, and that the original requirements had been met.

Re-sourcing of a suitable cable, following the raising of minimum order quantities to an impractical level, proved to be a surprisingly lengthy procedure. In the absence of documentation from the original design to explain the selection criteria, it was necessary to start from first principles to create a specification. It was apparent that the cable affected the resistance of the device, and consequently the rate of heat generation at the tip. Calculation and experimentation was required to ascertain the optimum cross sectional area - a process that would have been avoided had procedures for documenting the design process been in place originally.

The finished handle fulfilled all of the original design requirements, and autoclave testing of material samples and adhesives ensured that it would not fall foul of the same problems as the last incarnation. Compared to the Mark Hovell handle, the number of different components has been reduced from thirteen to seven, only one of which is machined. This virtually eliminates machine time, whilst assembly man hours has also been cut by around 40% due in part to the removal of brazing operations. Overall cost is dramatically reduced by roughly 75%, all of which can be converted directly to an increased margin, with the new handle selling for about the same price as before.

5.1.2 Heavy Duty Cautery Handle

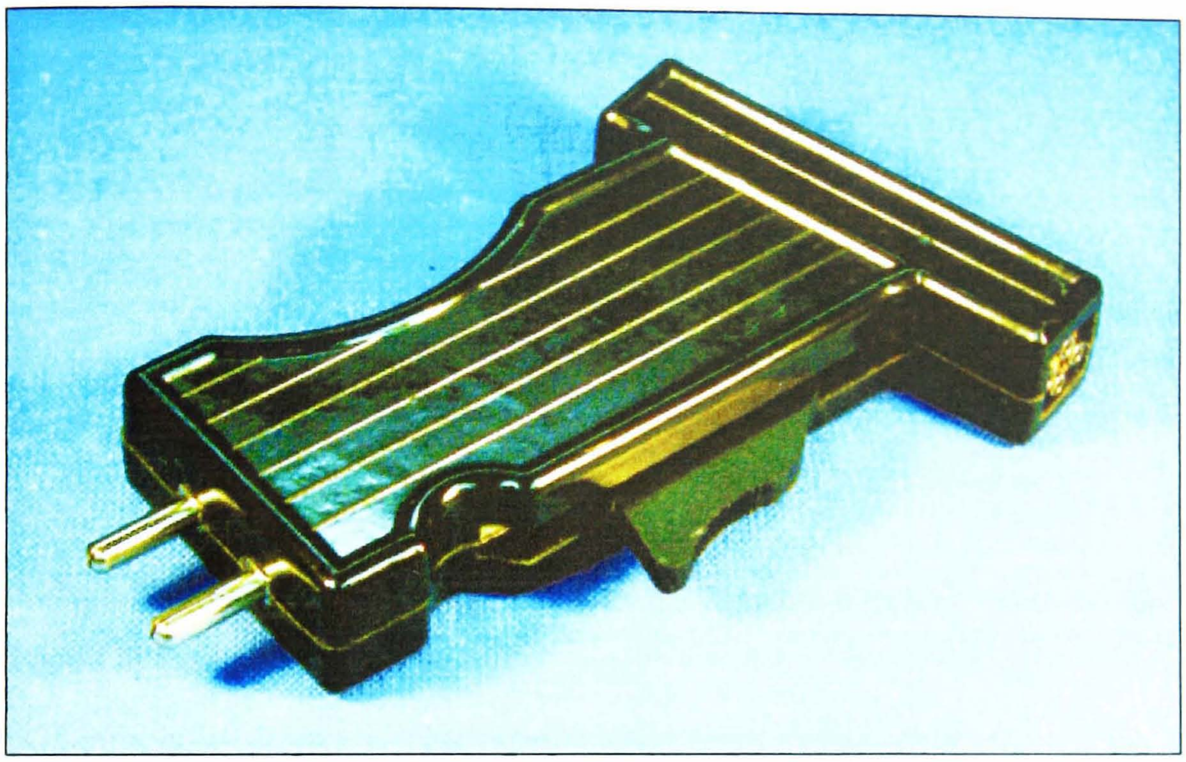


Figure 5.f Old Heavy Duty Handle

The old heavy duty cautery handle suffered from similar manufacturing issues to its little brother. However, its primary problems were that of aesthetics and ergonomics. The material used for the mouldings was Bakelite, the shape was most unforgiving on the hand after little use, and together these factors certainly made the product look its age. In fact the same handle had been produced for over 30 years, which explains the other problem that the mould tools were beginning to wear out.

Redevelopment was run in parallel with the light duty handle prior to hand-over. The first associate had once again worked with the CE team to choose a desirable shape for the new handle from 3D concept projections (Figure 5.g), and had also conducted market research by way of questionnaires with GPs to help create the original design specification.

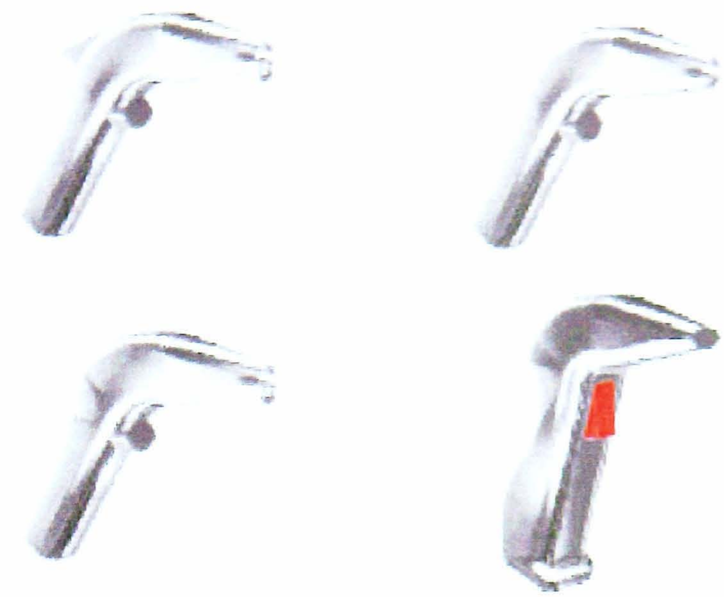


Figure 5.g Example 3D Concepts

Once the new handle shape was chosen, it was decided to use rapid prototyping (as explained in Section 2.2.1) to test its ergonomics. A mock-up of the light duty version had been made by machining, but the surface profile of the heavy duty handle was too complex for this approach. Furthermore, it was intended that RP would provide a route to create the mould tools needed for production.

At the point of project handover, the prototype handle (Figure 5.h) had been assembled, and proved to be an effective, if delicate working model, allowing assessment of the design aesthetics and ergonomics.

Figure 5.h Rapid Prototyped HD Handle

As stated, this and other projects were prioritised following handover. The heavy duty handle was moved down the list, with the intention of completing the light duty development first, and then applying the lessons learnt there to this project. However, subsequent meetings revealed dissatisfaction with the direction of the development. Interestingly, although the design had been widely accepted at the 3d visualisation stage, the rapid prototype revealed that the shape was too large and cumbersome. This fact, coupled with the experience from the light duty project of materials and manufacturing problems led to the decision to shelve the project.

5.2 Major Projects

5.2.1 Endoscopic Video Trolley

The first complete project undertaken by the author was the re-development of a powered trolley system for endoscopic video equipment. It provided a test case to assess the effectiveness of the concurrent engineering scheme, at the same time as addressing an urgent requirement for the company.

The agency agreement between Rimmer Brothers and their German partners primarily concerned the factoring of equipment for endoscopic surgery. Typically, when equipping an operating theatre for such procedures, a complementary system of video & image processing units will be required. This equipment is provided together with a trolley capable of carrying and powering it. The trolley will normally also have the facility to support a second monitor on an adjustable arm which the surgeon can position as required. Originally, the package was provided entirely by their partners, but Rimmer Brothers soon realised that offering their own design of trolley, at a somewhat lower price, would encourage more sales, whilst providing a proportionally larger income. Although the agency imposed some restrictions on the sale of directly competing products, this situation could be beneficial to both parties, and was therefore acceptable.

The original RB trolley development five years earlier typified the company's approach to certain design projects. Only a limited amount of time and resources were made available, and the product was rushed from concept to production in the space of a few weeks, most probably to satisfy an outstanding order. The result was a product that fulfilled the functional requirements, but it would be fair to say, had not benefited from a more in-depth exploration of manufacturing and aesthetic alternatives.

5.2.1.1 Project Initiation

The first concurrent engineering meeting regarding the trolley was held during September 1996. At this stage the rationale behind calling for a redesign was discussed between members of marketing, design, sales and manufacturing. With the endoscopy market representing a long term growth sector, and Rimmer Brother's increasing involvement in providing such equipment, it was agreed that sales of trolley systems would be assured, given the right product at the right cost.

Following this first meeting, a period of research was carried out before embarking on design work. A comprehensive understanding of the product was built up by accompanying sales representatives to hospitals to see existing systems in place, discussing requirements with surgeons, and conducting a review of competitors products. From this a design specification was created, using the new COP form, which accurately reflected the requirements of the user, whilst also highlighting other lifecycle considerations relevant to the design (see Appendix C for complete specification).

The most important points drawn from this research are listed below

- The existing design concept worked well, and was broadly comparable with other trolleys on the market
- The manufacturing costs, both financially and in terms of resource usage were excessive and highly inefficient
- The product aesthetics could be improved to demonstrate a more modern, high quality image to the buyer
- A number of functional improvements, highlighted in Figure 5.i, were required to provide a more competitive product

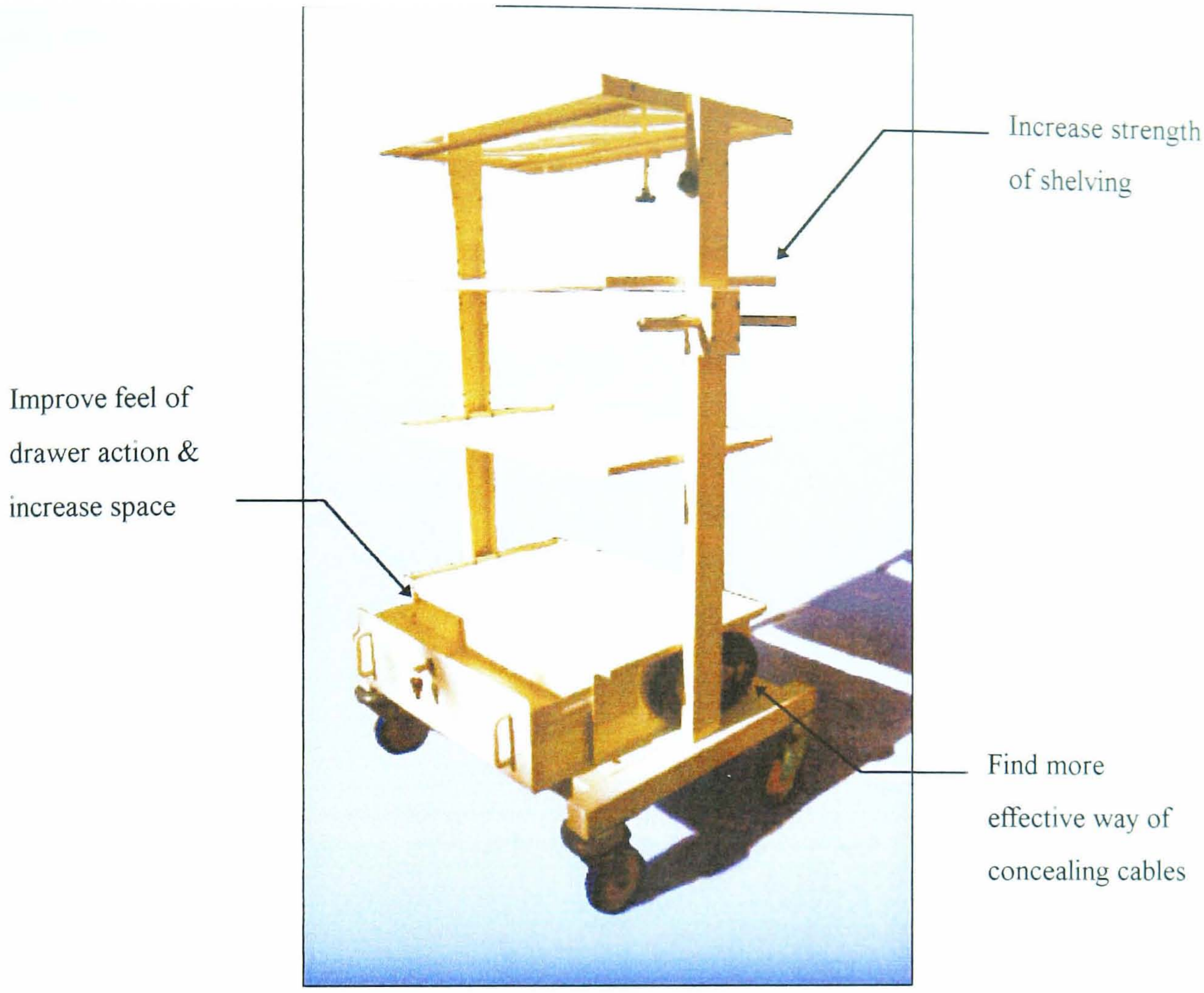


Figure 5.i Old Trolley Design

5.2.1.2 Design Approval & Concepts

Armed with these conclusions some concept ideas were sketched up prior to the second CE meeting. At the meeting the specification and concepts were discussed by a similar panel to ensure that people's original ideas and requirements had been accurately translated. Following some minor adjustments the design specification was approved, and the project given an official mandate to proceed.

Following this meeting, design work began in earnest. Preliminary concepts were concerned with the overall look and function of the trolley. About three or four of the best concepts were then expanded to include further detail regarding the specific manufacturing techniques and mechanical function. Each idea was assessed objectively by the now formalised 'Fluid design team'. In practice, as discussed in Section 4.2.3.2, this was a more informal discussion with only those members whose immediate expertise was required. In this way, design progress could be monitored on a more frequent basis to ensure that manufacturing, assembly and functional considerations were being addressed. Although not all of these meetings were fully minuted, the fundamental decisions effecting the direction of the design were recorded.

The following sub-sections discuss in detail the rationale behind the decisions made during the development process for each major component group. Although ultimately these choices were the responsibility of the designer, it is important to realise that they were frequently aided by consultation, and ultimately based on the compromise born out of consideration for relevant lifecycle elements.

5.2.1.3 Frame Design

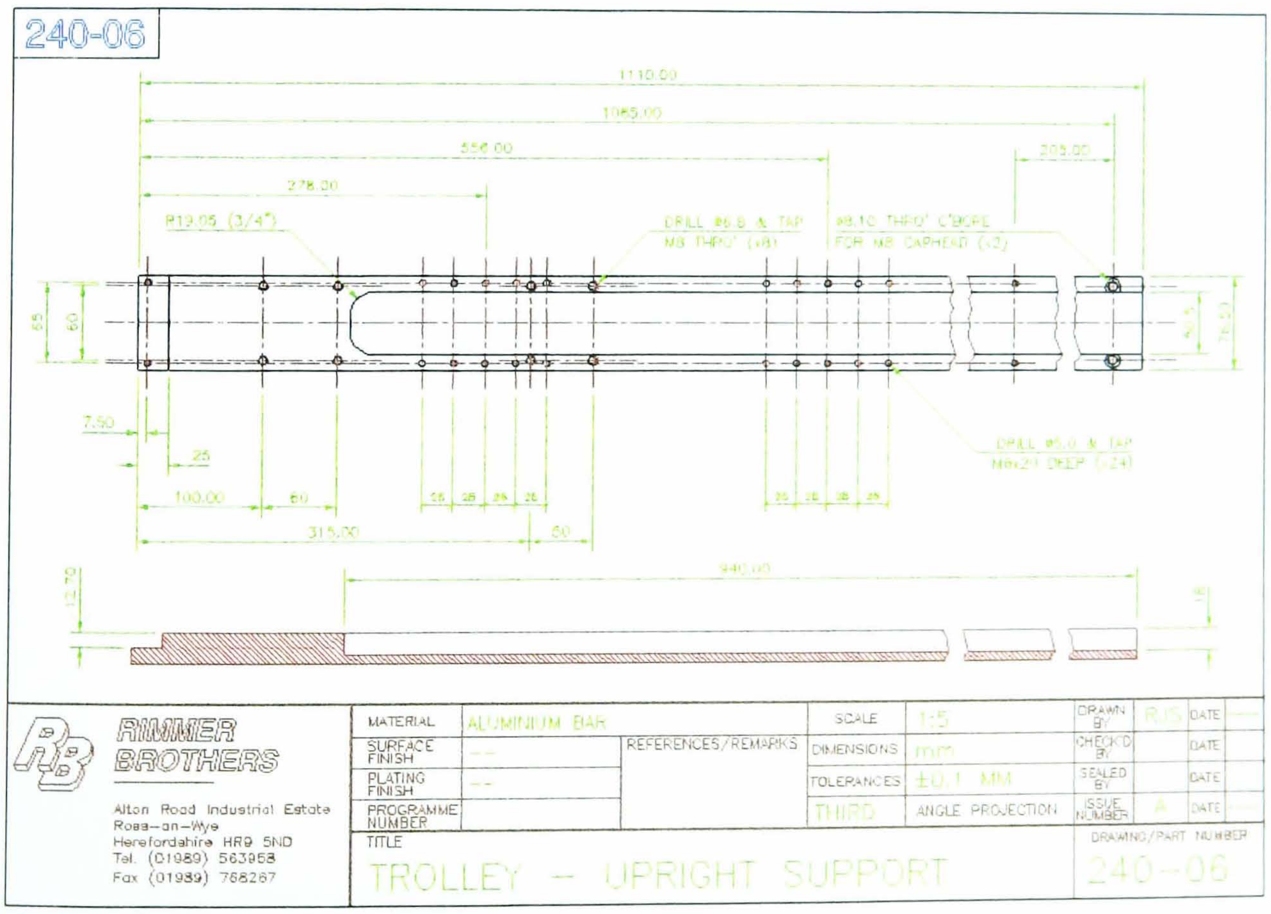


Figure 5.j Original Frame Upright

The most natural part to work on first, the frame also represented one of the areas most in need of improvement. The original frame consisted of six bars of aluminium extensively machined, and bolted together. A single complete frame represented at least seven hours of machining, and a further two hours finishing work prior to painting. The amount of material removed during milling was far in excess of economic figures. Furthermore, this approach to manufacturing prevented the design from incorporating much in the way aesthetic appeal, instead resulting in a highly angular shape.

Having investigated the cost implications, it was decided at an early stage to switch to an aluminium extrusion, which it was hoped would, with little modification, be able to form the basis for both the uprights and the base frame. Additionally it was the intention that such an extrusion could be cut to any length allowing for a modular set of trolley variants. Custom extrusions are becoming an increasingly cost effective alternative to off the shelf designs, and so work began on creating a profile tailored to the product's specific needs. Early concepts were based quite heavily on the original frame's design (Figure 5.k.a), but as the designer became more aware of the capabilities of extruders, a more radical approach was adopted, which incorporated both aesthetic and functional characteristics (Figure 5.k.b-e).

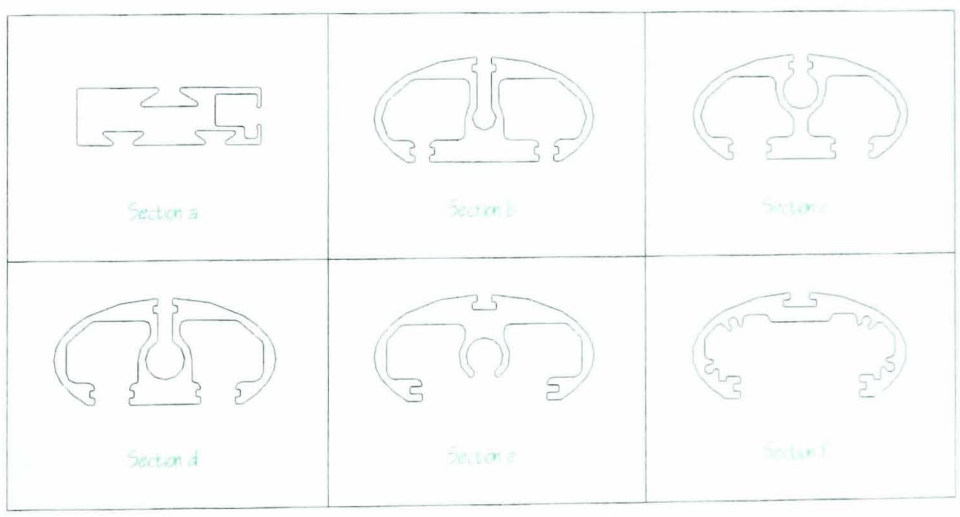


Figure 5.k Evolution of Aluminium Extrusion in Cross Section

The final section design, Figure 5.k.f, represented the best compromise between cost/unit length, strength and functionality. It is capable of accepting mains cabling, has two channels to mount shelves at any height, and will accept self tapping screws to mount an endplate with no need for additional machining. This section was to be used for all the structural members, both on the trolley, and its peripheral monitor arm. Beyond the machining of mitre joints at its ends, no further modification was necessary, and the surface finish obtained from extrusion is quite sufficient to accept powder coating without any further work. A comparison with the old design revealed that to build one frame assembly, a reduction from 7 to 2 overall man hours had been achieved, whilst cost had been reduced by almost 50%.

5.2.1.4 Shelf Design

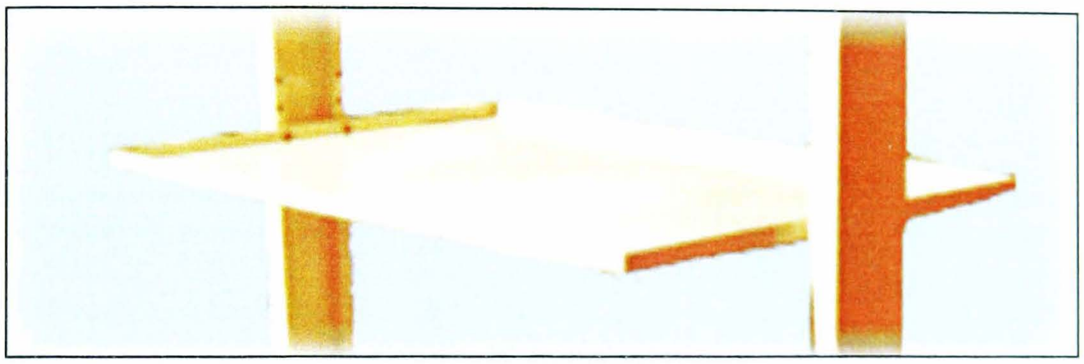


Figure 5.1 Original Shelf Tray

The old shelving design was also quite labour intensive, involving the machining of four side bars which were then welded to a sheet of aluminium. This welding process created large amounts of excess weld which subsequently had to be machined away to re-achieve the desired shape. The finished shelf was once again unforgiving on the eye, but more importantly also suffered a degree of warpage during welding, and was insufficiently strong enough to support the 30kg load of a large monitor without further strengthening.

The concept ideas for the new design were instead based around a fabricated sheet metal construction which would improve strength and rigidity whilst reducing the amount of labour input. To improve visual appeal however, a compromise was sought whereby the shelves would carry through the two tone colour scheme, common to other RB products, that had been devised.

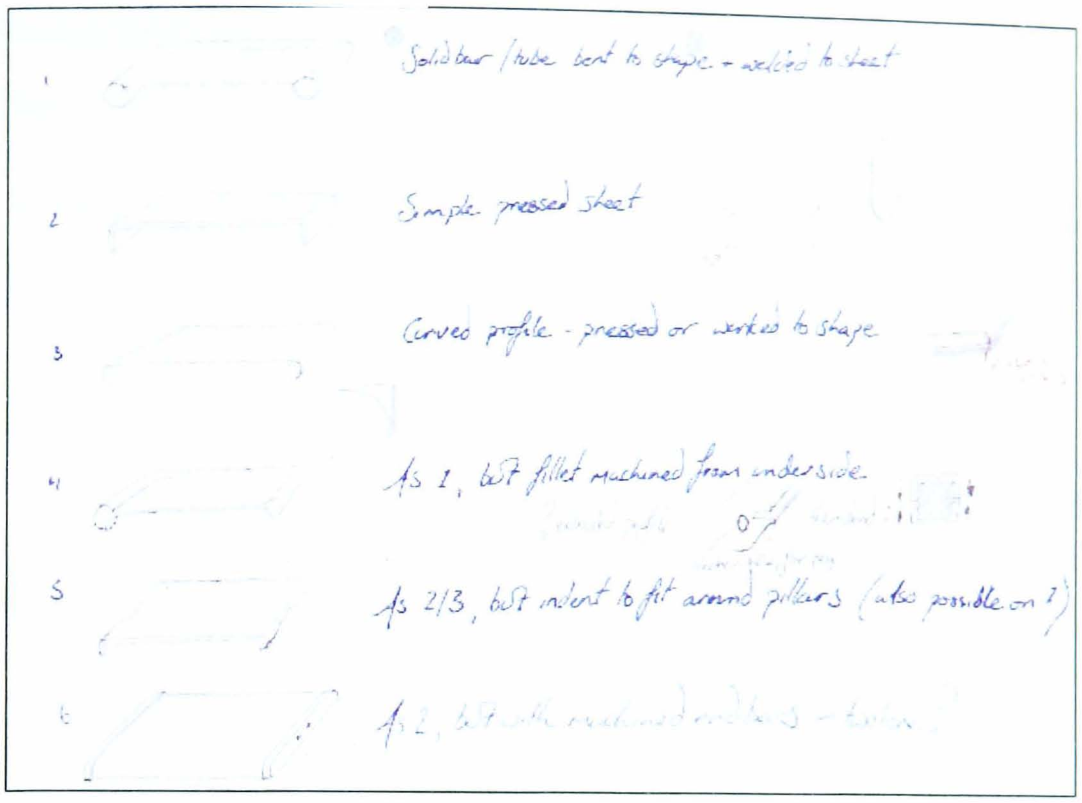


Figure 5.m New Shelf Concepts

Following lengthy debate with representatives from both in-house manufacturing and the external fabrication suppliers, the conclusion was to resort to machining end plates which could be powder coated in a different colour. Features of the design shown in Figure 5.n include increased tolerances to ensure a good fit, whilst reducing rejects; brazed brackets on the underside to reduce number of fasteners and modification of the end bar to allow single pass machining.

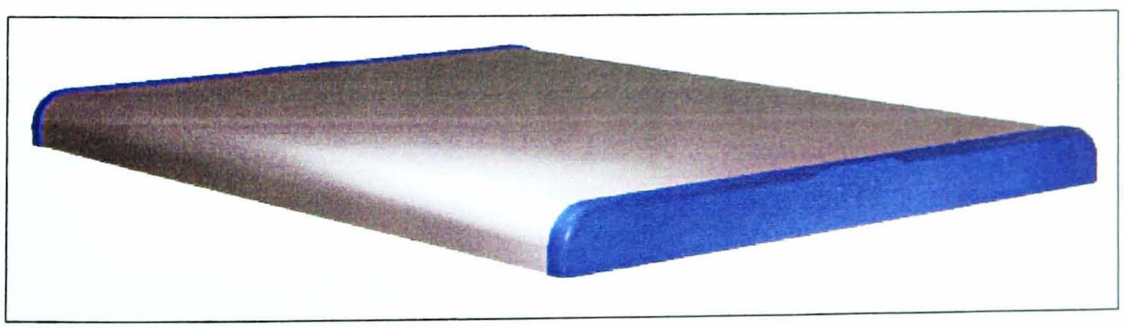


Figure 5.n New Shelf Design

This compromise did increase machining time back to a similar level as compared with the old shelves, however their disadvantage was in the 7 hours of finishing work needed - a requirement that no longer existed with the new design. Overall the new version looks and performs far better than its predecessor, and costs around 30% less.

5.2.1.5 Base Unit Design

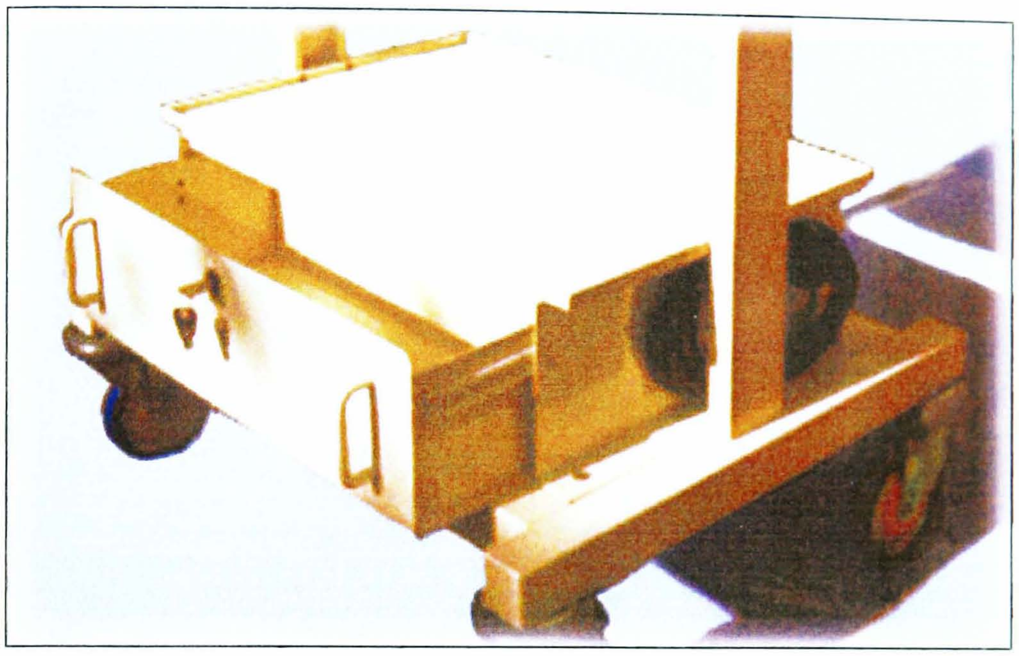


Figure 5.o Original Base Unit

Three primary problems existed with the old base unit design. Electrical safety standards and customer requirements dictated the use of an isolating transformer through which the on-board equipment was powered. In the original design, the size of this transformer was severely limiting the depth of the drawer. This had the knock on effect of compromising the action of its runners, which had to be manufactured in-house, and custom fitted to each unit. Thirdly, the distribution panel and cables supplying each unit were exposed and unsightly.

The solution to these problems was to re-source the transformer, and mount it underneath the base unit. This would also have the added benefit of lowering the centre of gravity for the trolley. With the additional space now available inside the unit, the drawer could be extended, and the distribution panel enclosed. Once again, development was carried out in close liaison with the fabricators, thereby arriving at a design which was easier and most cost effective to make.

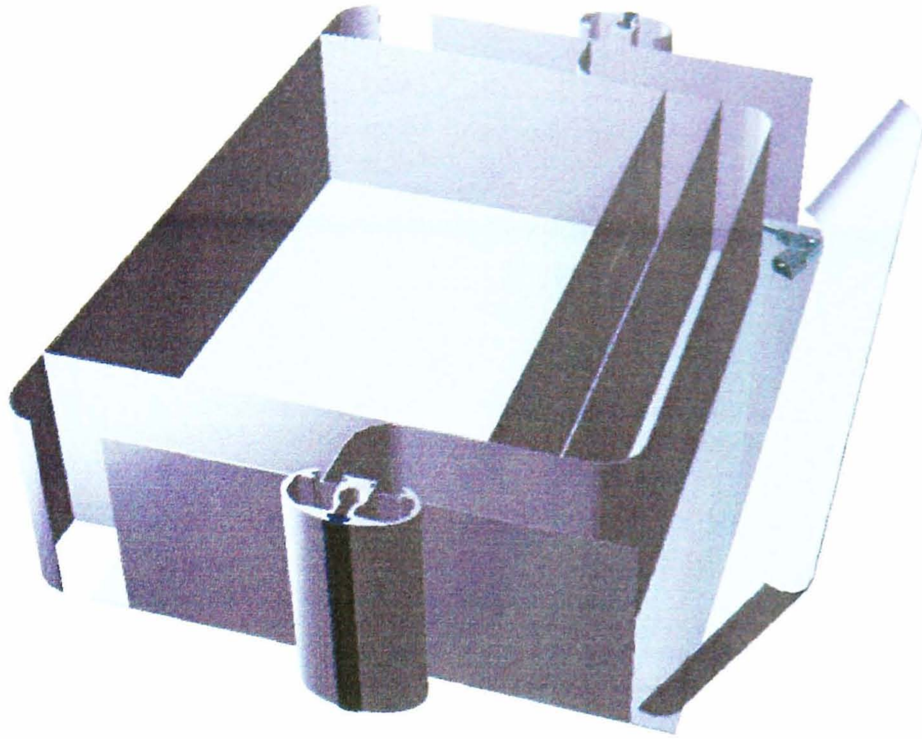


Figure 5.p New Base Unit

In terms of manufacturing, being out-sourced there is little change in time or cost between the old and new enclosures, although buying in drawer runners saved roughly 1 hour's milling work. The significant improvements can be found in terms of function, aesthetics and assembly time.

5.2.1.6 Summary

Together with the other components that make up the new design, the cost was reduced by approximately 20%. What is more significant however, is the reduction in labour costs during manufacture and assembly of around 50%, coupled with the improvements to the appearance and function of the product, including variable height shelf fixing, large smooth running drawer and internal cable routing.

5.2.2 Halogen Light Source

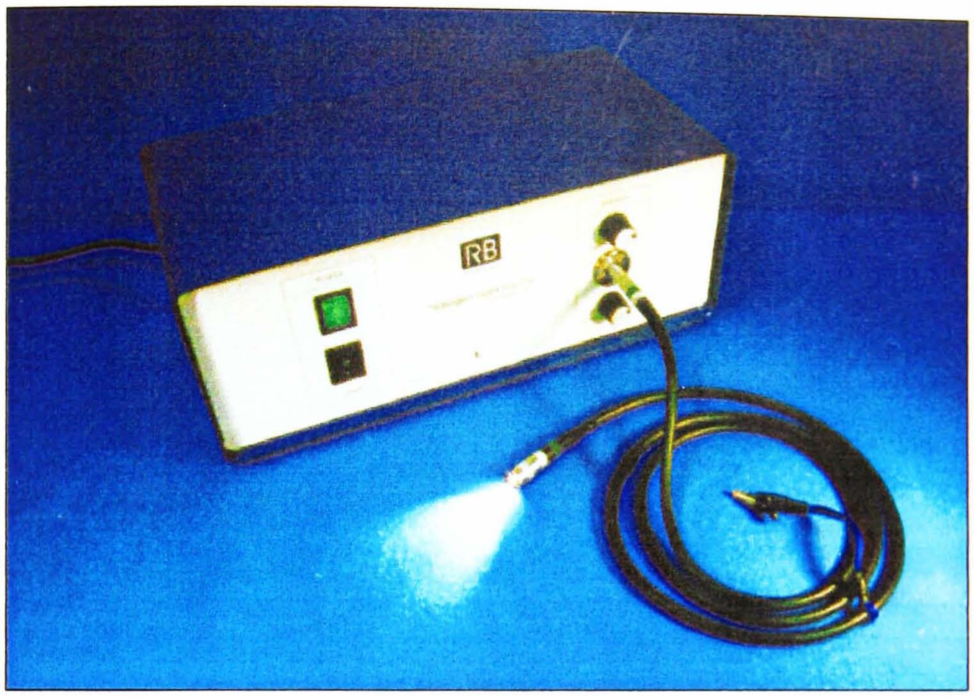


Figure 5.q Typical Light Source

5.2.2.1 Preamble

Keyhole surgery relies on high power illumination to provide sufficient light transmission through the very small fibre optic channels of endoscopes. Although there is an increasing trend to use xenon and other gas discharge lamps for this purpose, traditional tungsten halogen bulbs are still the cheapest and most widely used means of illumination. Rimmer Brother's range has for a long time included such light sources, however they were originally designed as an alternative to battery illumination of non-invasive instruments such as laryngoscopes and rectoscopes, and as such do not provide enough light for endoscopic applications. It was therefore decided to introduce a high power, 250 watt version into the range to supplement the existing 100 and 150 watt units.

Although the principles and technology involved were common to the other two units, dealing with the increase in size, weight, and heat generation prevented the common use of their components, and so this project would be approached from a clean slate.

Due to other pressures, the management decided to enlist the services of an engineering student working through the Shell Technology and Enterprise (STEP) scheme to conduct the primary stage of the development up to and including the creation of a first prototype. Following this, the project would be brought to a conclusion by the author.

5.2.2.2 Design Specification

Prior to the STEP scheme, a CE meeting was held to discuss the requirements of the unit. Representatives from sales, marketing, manufacturing and design worked together to create the detailed specification that would form the brief for the student to work from. The fundamental points are listed below:

- Twin lamps, with switching or mechanical changeover to provide backup should one fail
- 250 W tungsten halogen lamp with integral dichroic reflector to reduce parts
- Mechanical as opposed to electrical intensity control
- Step down transformer supply avoiding need for complex electronics

The underlying aim was to keep the unit as simple as possible, thus improving reliability, keeping cost low, and allowing the use of existing, proven technologies.

5.2.2.3 Primary Stage Development

The STEP student worked with the company for approximately two months, during which time he explored various ways of mounting and switching between lamps, before developing one concept through to the prototype stage.

Unfortunately however, the STEP scheme imposed an alternate set of priorities on the work carried out. The pressure to complete the prototype development within the space of the two months meant that there was precious little time to consider certain alternatives, and to learn and apply concurrent engineering techniques. The result was a device that, although functionally adequate, bore little consideration of aesthetics, manufacturing efficiency, ease of assembly or compliance with safety standards. Although not denying that the work carried out was valuable, it transpired to be little more than a starting point for full development. In fact this period of work was not dissimilar to Rimmer Brother's old process of single track design described in Section 4.1.1.

5.2.2.4 Secondary Stage Development

During the secondary stage, several informal CE meetings helped to define ways of improving manufacturing efficiency. The most fundamental of these involved the block that housed the gear assembly.

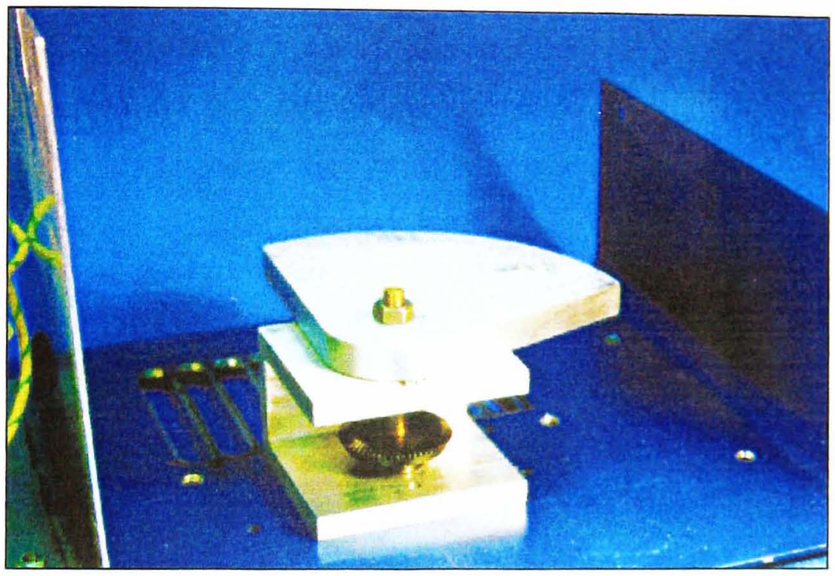


Figure 5.r 1st Generation Gear Mechanism

Figure 5.r shows the changeover mechanism. Using two bevel gears, a knob on the front panel rotates the backup bulb in to position when required. In order to overcome the requirement for substantial machining with the original housing, it was replaced with a fabricated sheet metal channel.

Figure 5.s 2nd Generation Gear Mechanism

This channel also helped to direct air flow across the lamp, and was designed to improve the feel of the mechanism - replacing the ball plunger lock with a spring and end stops (Figure 5.s).

The second major change involved the intensity shutter assembly, which on the original design was made up of several machined parts, and a length of gear rack brazed to the shutter. By contrast, the new design did away with the need for a separate shutter guide, by incorporating it into the supporting heatsink. Although this increases the complexity of one part, the number of operations (each one requiring re-mounting and datum setup) required to make it remained the same. Meanwhile two other parts were no longer required. The shutter itself has been modified to allow it to be pressed from sheet material in one shot - eliminating the need for machining or brazing.

The other factor that was considered during this phase was ease of assembly. It was decided to involve those people who would be responsible for production assembly midway through the second stage. Whilst building a new prototype, problem areas were identified, and (mainly constructive) criticisms noted, so that when the design was finalised, the unit would be as easy to assemble as possible.

The finished product represents a considerable improvement over its first incarnation, both in terms of reduced cost and ease of manufacture and assembly. Without an established predecessor, comparisons like the previous projects are obviously not possible, however the original specification has been fulfilled, and those involved believe that the product is both cost effective and desirable to consumers.

5.2.3 Contraceptive Device

5.2.3.1 Preamble

The remaining project that was undertaken as part of this scheme was somewhat different in its initiation and development. Rimmer Brothers have a reputation in the medical world for being able to support and develop new ideas originating from doctors or surgeons themselves. This was actually the way in which the earlier version of the light duty cautery handle was developed, as is evident from its name - the Mark Hovell Handle. In some ways this form of development is inherently concurrent since it involves continual communication with the end user, whilst relying on the company to supply manufacturing and sales knowledge.

This project involved the development of a new form of medium term, removable contraceptive. Had the project been successfully completed, its potential usage would have been great, however questions over funding led to its eventual shelving. Because of this, certain details remain bound by a confidentiality agreement, and will be omitted.

5.2.3.2 Development

This project was initiated by a surgeon from a London hospital who contacted the company in early 1997. Prior to the meeting he had written a short paper on the broad details of his concept, which had been used to secure a preliminary patent for the invention. Rimmer Brothers were commissioned to develop the idea into a working prototype which could be used to conduct preliminary trials.

From the outset, the designer was involved in direct discussion with the surgeon, and regular meetings were held to ensure that development of the device progressed as per his intentions. CAD was once again helpful to communicate ideas and concepts between parties by way of 3D modelling. Since the device would be introduced using endoscopic equipment, designing with computer also hastened development of components, whose size and accuracy were critical.

Manufacturing considerations were somewhat different with this project. In production, is was expected that the device would be produced in volume using moulding techniques. However for the prototype, it would have to be machined, and so although CE meetings were held to ensure this would be possible, it was important to bare in mind the mass production processes which could also be used. Materials were chosen to fulfil both these requirements, whilst also being appropriate to the environment in which they would be used.

Before the project was halted, a completed prototype was tested by the surgeon, and early results were encouraging. Although somewhat tricky to machine, it would have been ideally suited to volume production techniques.

5.3 Summary

This chapter has described the application of the tools and techniques discussed in the last chapter during five development projects conducted over the space of two years.

The big three projects show design improvements with respect to manufacturing costs and functionality, certainly due in part to lifecycle considerations afforded by the use of teamworking:

- Cautery Handle: >90% reduction in manufacturing time; 75% cost reduction
- Trolley: 50% reduction in manufacturing costs; improved functionality
- HLS Light Source: Low manufacturing cost; simple, functional design

Some projects, such as the cautery handles, have encountered problems which may have been avoided had the process been more effectively applied. However, this scheme has been conducted on the basis of a learning process, and some of the best lessons are learnt through mistakes. The valuable experience gained through these projects will form the basis for an in depth discussion of the effectiveness of the scheme in the next chapter.

6 - Discussion & Evaluation

The previous two chapters have described the work carried out by the associates during a total of four years with Rimmer Brothers. This final chapter will provide a summary of this work and discuss its impact on the company, before offering conclusions with regard to both how successfully the aims of the scheme have been fulfilled, and how the lessons learnt may help organisations of similar size when considering CE as a design methodology.

6.1 Scheme Overview

Prior to the start of this programme, representatives from both the university and Rimmer Brothers identified and discussed problems facing the company. It was noted that similar issues affected many companies, regardless of their size and nature of business. This led to the proposal that the concurrent engineering techniques used to tackle these problems in large organisations could possibly help smaller companies, given the appropriate resources and training. The original programme that was set up by the TCS was intended to provide the environment to test this theory, sharing the same targets of reduced lead time and increased quality. The precise nature of the new development procedure was left to the discretion of the associates, who would base their selection on predicted relevance, then modify the implementation of these techniques based on subsequent experience.

Following a number of product development projects carried out during the four year programme, an assessment could be made to ascertain how the application of CE techniques had affected the product development process. By developing a deep understanding of CE, Rimmer Brothers and how the methodology and company interacted, it was the intention that objective and generalised conclusions could be drawn that would be relevant to other companies.

Over the course of the scheme, three design projects have been carried through to completion. A further three reached the prototype stage before being shelved, whilst a handful of other smaller projects received some time input. A significant amount of time was also spent developing procedures and commissioning and administering IT systems which would support the concurrent engineering environment. The timeline shown in Figure 6.a illustrates these interactions of the scheme with the company, showing what has been achieved, when, and with what new resources.

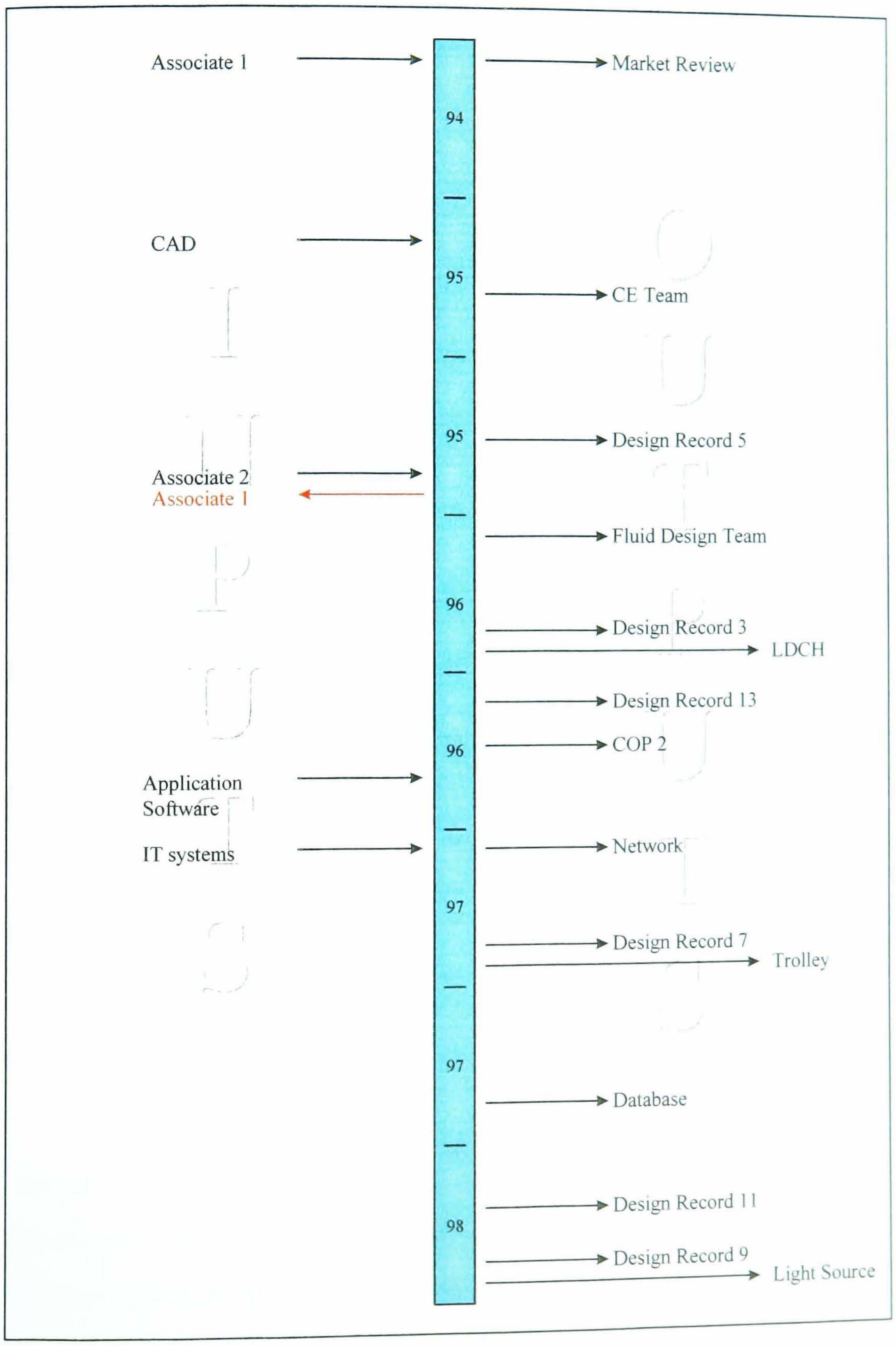


Figure 6.a Time Line

6.2 Effects on Products & Resources

It was stated in Chapter 2 that CE is commonly introduced in large companies with the aim of making better products more quickly. It was hoped that by implementing CE in the small company environment of Rimmer Brothers, they too could achieve their objectives of:

1. Improving the quality of their manufactured products
2. Speeding up development of new products

In assessing how effective CE has been in achieving these goals for Rimmer Brothers, and consequently whether or not it may be an appropriate tool for use in other companies of similar size, a comparison of old and new processes and products will be made, with regard to the objectives laid out above. Before embarking on this analysis, it is helpful to visualise the entire development arena, which can be fully described with reference to the areas laid out in Figure 6.b and Table 6.A below.

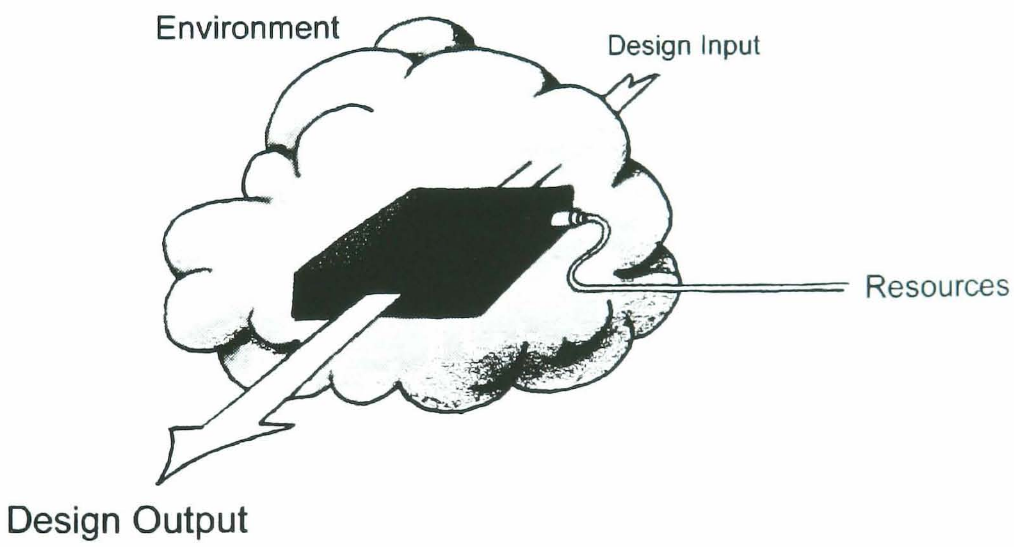


Figure 6.b Design Arena

This diagram shows the design process as a 'black box' which accepts design inputs such as customer requirements and design specifications, and converts them into design outputs, being product design drawings, manufacturing instructions etc. In order to achieve this, the box uses resources - primarily time, money and people. Completing the picture, this process is carried out in a specified environment, defined by characteristics including company size & culture, market factors and product sector. Some of these areas are fixed, and independent of influence from process re-engineering, whilst others are very much dependent on changes within the design process black box. Table 6.A summarises this information and shows how changes in one area directly affect others.

	Active Change				
Passive Result	Design Inputs	Design Outputs	**Design Process**	Resources	Environment
Design Inputs	×	×	×	×	✓
Design Outputs	✓	×	✓	✓	×
Design Process	×	×	×	✓	✓ E3
Resources	×	✓	✓	×	✓
Environment	×	×	×	×	×

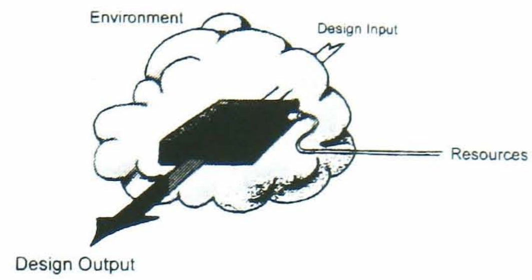
Table 6.A Design Arena - Interrelation of Divisions

Reviewing this table, it becomes apparent that the design process is affected by changes in resources and environment, and conversely changes to the process will affect output and resources. Also of note, the two areas of input and environment are largely independent of other changes.

It is now clear that to assess the results of this thesis, it is necessary to analyse (a) The effects of process changes on design output and required resources, and (b) The influence of resources and the environment on shaping the design process. Whilst Section 6.3 examines the influencing factors, this section is concerned with the first of these topics - the 'passive' results of process change.

Referring these areas to the aims of the scheme, design output can be seen to be analogous with product quality since improving design output essentially means designing better products that progress through their lifecycle in a more effective manner. Resources include the fundamental variable of time, and so analysis of this area will reveal how lead times have been affected.

6.2.1 Product Quality



Improvements in product quality can be made by altering any combination of elements that affect how efficiently it moves through its lifecycle (refer to Section 1.3.2). Reference to Figure 2.f (pg 23) reminds us that each lifecycle stage can be associated with certain design characteristics, and that changes to these characteristics are what will ultimately affect product quality.

Manufacture and use are commonly targeted as the lifecycle stages which most fundamentally influence the success of a product. Therefore, design characteristics associated with these stages provide the clearest criteria for comparison of new & existing products. Since coincidentally two of the projects completed during this research were re-design based, a like-for-like study is possible:

Table 6.B shows marked improvements in both projects, averaging more than 50% reduction in manufacturing and assembly time. Statistics like these are comparable with the results from large companies e.g. Digital's claims of a 50% reduction in product costs (originally quoted on page 29).

In summary, including the other projects described in Chapter 5, products designed during this four year scheme are characterised by:

- Fewer parts
- Simpler parts
- Less manufacturing operations
- Faster assembly
- Better functionality
- Improved aesthetics

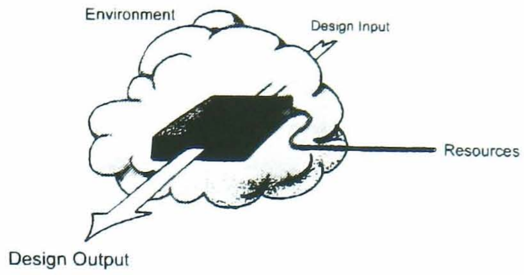
Project		Parts	Manufacturing time (mins)	Assembly time (mins)	Production Cost (£)	Additional functional features	Aesthetic features
Light Duty Cautery Handle	Old	18	80	30	33	-	Sharp edges; Uncomfortable; Solid build
	New	7	8	18	9	=	Smooth lines: Ergonomic shape and feel
	Percentage Change	**60%**	**90%**	**40%**	**73%**		
Trolley	Old	=	600	420	860	-	Boxy; Characterless
	New	=	300	120	760	Adjustable configurations; Larger drawer; Increased strength	Smooth lines; Tidy cable routing
	Percentage Change	**0%**	**50%**	**71%**	**12%**		

Table 6.B Product Comparisons

Chapter 5 quotes several examples of how a different mindset, and meaningful dialogue between departments and customers has resulted in the creation of products with fewer parts, parts that are easier to manufacture and assemble, and products that are perceived to be more attractive to customers, fulfilling their genuine needs, and offering worthwhile additional features.

The period of this research has not been long enough to ascertain whether and to what extent such improvements in quality will translate into increased sales and profits, but all those involved predict positive results, and if sales were to remain at the same level, the reductions in manufacturing costs would directly increase profits.

6.2.2 Process Resources



The design process has been fundamentally re-structured as a result of this scheme, the details of which will be discussed in Section 6.3.1. The table (Table 6.C) below shows how these changes have affected the draw on company resources.

Old methods	New processes
Manpower resources	
Diverted from other duties, which may suffer as a consequence	Dedicated engineer, drawing on other team members as required
Design Process Costs (financial resource)	
Minimal assigned resources. Multiple prototyping often required	Dedicated design engineer represents significant cost addition. Prototyping cost reduced
Project Length (time resource)	
2 weeks - 2 years dependant on circumstances and urgency	Typically 12-18 months. Less flexible, but more predictable

Table 6.C Comparison of Design Processes

Undoubtedly (and predictably), the number of man-hours devoted to design has increased as a result of the scheme. Previously, the general manager in Ross and the quality manager in London typically devoted 33% of their time to design tasks, equating to 66% of an employee in total. There was effectively no input from other employees. Under the new set-up man-hours have doubled, with a full time design engineer, and regular contributions from other departments as follows:

Department	Contribution (% of FT employee)	
	Old System	New System
Design	-	90%
Manufacturing	33% (in design capacity)	20%
Quality	33% (in design capacity)	10%
Sales	-	5%
Marketing	-	5%
TOTAL	66%	130%

Table 6.D Detail of Manpower Resources

Further discussed in the next section, it is important to point out that a strategic decision by Rimmer Brothers to employ a design engineer accounts for 90-66 = 24% of this increase, whilst the remaining additional 40% is as a result of using CE teamworking techniques.

The direct allocation of finance to the design process consists of three predominant factors: Salaries, Prototyping & Third party testing. It is clear from Table 6.D above that the salary element has doubled (assuming all contributors draw a similar wage). The nature of Rimmer Brothers products maintains prototyping as an essential element of design, however there is evidence that the expenditure on prototypes is reducing. Although the cautery handle went through an unfortunate additional design iteration, each iteration benefited dramatically from 3D modelling prior to tool making. Without this aid, it is likely that several further iterations would have been needed to perfect the shape and fit of the design. Similarly with the trolley, collaboration with fabricators and extruders ensured that the first trolley to be built was suitable for demonstration, and proved to be almost identical to the production model. Typically, where three prototypes were common before, CE techniques are expected to cut out the need for the third, if not second prototype. Third Party testing will remain a necessary overhead, but once again, there may be occasion where an increasingly close relationship with the test house during development may avoid a situation where the unit fails at this late stage, leading to costly re-testing.

The question regarding changes in development time is quite complex, and results are not as clear-cut as those concerning product quality. Project Length was a genuinely unquantifiable variable under the old system, and depended as much on the project in question, as the people asked for opinion (incidentally highlighting the issue of lack of documentation). A comparison is further trivialised by the fact that it is meaningless to compare individual lead times. Complex products will inevitably take longer to develop that simple ones, and any one project may suffer from a delay unrelated to the method of design. Hence a statistically significant difference can only be calculated by averaging lead times for a large number of projects before and after process changes. However, in the absence of such data qualitative conclusions can still be drawn from experience.

1. Firstly, where previously little regard was given to optimisation for manufacture, cost and intended purpose, the time now spent collecting data, discussing options, and considering these lifecycle factors can only serve to slow down the development process.
2. Furthermore, whilst there is now an extra person, devoted to product development, he is also responsible, under advisement, for manufacturing and assembly process design. A larger company would potentially be able to spread these functions between members of a dedicated MDT, but for Rimmer Brothers pressure on resources prevent such a truly simultaneous approach, and much of the benefit discussed in Section 2.1.3 of time compression is lost.
3. At the same time this scrutiny should reduce the likelihood of delays due to late design changes (whilst CAD would speed up any such alterations), but the relevance of this situation is suggested to be proportional to product complexity, and has rarely been a major problem for the relatively simple products manufactured by Rimmer Brothers. As compared with the knock-on effects of late design change in a complex project such as automotive design, it is again clear that these benefits are somewhat diluted.

4. Finally, the implementation of any new system takes time to adjust to, as those involved are brought up to speed by training and experience.

The graph below is intended to illustrate the results of the scheme in terms of output and resources (relating to the two original aims) Although not quantitatively based, it is a graphical representation of the experiences discussed in this section. It shows a rapid increase in product quality, but an associated increase in lead times. Factor 4 above accounts for the prediction that these times will reduce in time, but it is unlikely that projects will ever be completed as fast as under the old process.

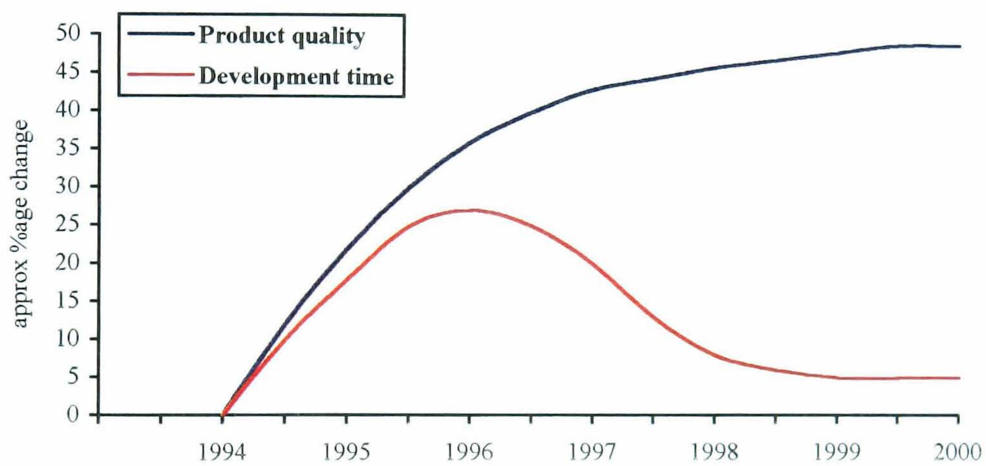
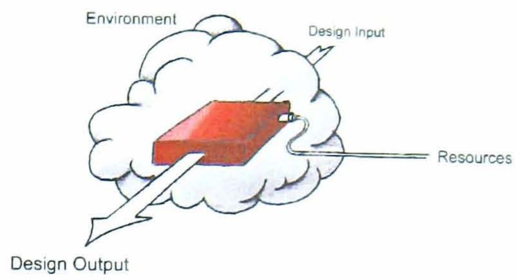


Figure 6.c Time & Quality Improvements

6.3 Influencing Factors

Before embarking on the implementation of concurrent engineering in Rimmer Brothers, it was important to understand the nature of both CE and the company. Only by appreciating how both facets may affect each other could implementation hope to succeed. Further to this however, with little previous experience with small companies to base the CE scheme on, it was almost inevitable that some amount of reshaping would be required as time progressed. The change of associate provided such an opportunity, however in practice the programme has been characterised by a continual process of experimentation, assessment and modification.

6.3.1 Effects of CE Implementation



In assessing the effects that CE has had on product development and the company as a whole, it must be reiterated that a certain amount of 'noise' interferes with the analysis. This is the result of artefacts due to the external interactions with the teaching company scheme. The most significant of these is the addition of the design engineers. Their presence is not related to the introduction of CE, and yet their influence has been greater than any other single change that has taken place. However, as long as this is accounted for (as with the analysis of manpower and financial resources in the last section), it should not diminish the validity of this assessment.

The following tools have been applied as a means to facilitate CE during the scheme

- **Teamworking**: The company now uses a multi-disciplinary team to help develop products 'right first time'. This team consists of a core of four members, but in effect draws information to aid decision making from any relevant source within the company
- **'Brainstorming'**: Whether individually (see later), or as a group, those involved in the design process attempt to consider as many concepts as possible during early development
- **Information Technology**: The design department has at its disposal a number of modern computer based tools to aid both the speed and quality of product development, including CAD, a supplier database and a system network
- **Documentation Procedures**: In order to help future developments, all documentation created during the design process is retained in a design record. Procedures have been created to ensure these records are maintained.
- **Design Flowchart**: The company operating procedure for design has been summarised in an easily understood flowchart which also helps to define responsibilities during development.

6.3.1.1 Teamworking

Without doubt, the most influential effect on both product development and company culture has been the creation of the design team. In both its guises, the team has helped to propagate throughout the company a sense of value and inclusion for those who have been involved, whilst their feedback has promoted consideration of lifecycle elements which in turn has improved product quality. As discussed earlier, the team has not worked in the traditional sense of a group of people dedicated to the design of a product, but instead has provided a forum for regular debate between departments with the intention of finding the best compromise for each major design decision.

Although the original team was somewhat helpful, it suffered from an overly formal structure. An enforced meeting of all members led to frustration on occasion when the development was at a point where expertise from some of those present was not needed. Conversely, delaying decisions, or making them without consultation when a meeting was not possible also led to problems. By comparison to the 'over the wall' approach to design discussed in Section 2.2.1, the original team appeared to work little differently - making uninformed decisions, and then 'throwing them over the walls' to different departments at each meeting to see if they get thrown back. This is perhaps where the light duty handle fell foul (Section 5.1.1.2), whereby more frequent and relevant discussion with manufacturing and the customer could have averted the problems of poor materials selection.

The fluid design team has been seen to work far more effectively, especially thanks to the closer ties with manufacturing. Returning to the wall analogy, now those walls are more like garden fences, over which it is far easier to chat about any problems at any time, and agree that a design won't get thrown back. The trolley project has been a good example of this, notably where the design of its handle (Figure 6.d) would not have attained the balance between aesthetics and ease of manufacture without working closely with machinists on the shop floor to understand the machine's limitations, and work around them.

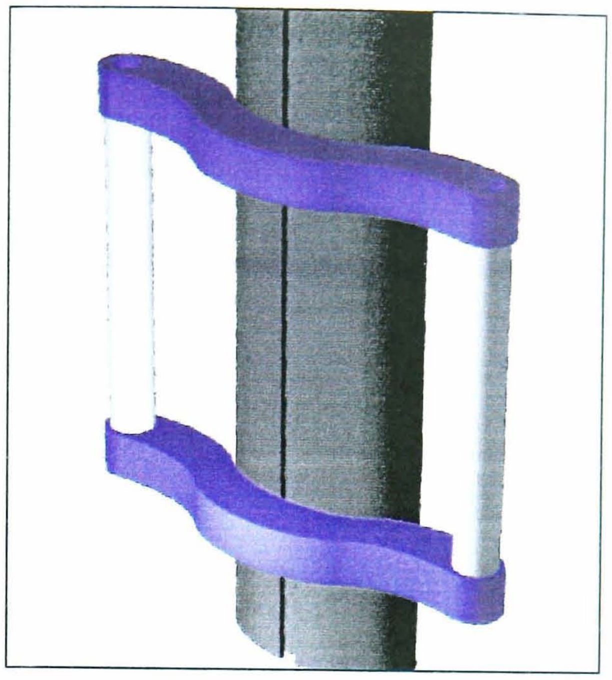


Figure 6.d Trolley Handle

6.3.1.2 Brainstorming

This also highlights the effective use of brainstorming. Three or four concepts were bounced around before it was agreed that the version illustrated above was the best. Once again, implementation of this technique has been less conventional. Explained in Section 2.2.1 brainstorming is thought of as a group activity, but in Rimmer Brothers it has been found to be equally effective if individuals are presented with a problem. This way, more efficient use of time can be made when they later meet to discuss alternatives, and with each participant having thought through the problem, the meeting is less likely to be hijacked by the one or two quicker thinkers. This approach has worked very well, a particular example of which was seen during the trolley fabrication development. As stated in Section 5.2.1.5, the sub-contractors were incorporated into the fluid team. In reality, phone calls, faxed sketches and CAD files were bounced back and forth before arranging face to face contact. This resulted in all parties contributing meaningfully with well thought out ideas during the meeting.

6.3.1.3 Information Technology & Documentation

Design documentation is a new concept for the company, and one that some find hard to appreciate. In larger companies, design projects can involve many personnel potentially separated by location or division. Subsequent projects often make use of components from previous designs, and employee turnover is more frequent. Each of these factors contribute to the need to thoroughly document the decision making process to help colleagues, or prevent future projects from falling foul of the same problems. Despite the fact that these issues are of less relevance to Rimmer Brothers, there is an additional factor which now makes such documentation not just helpful, but essential, namely the requirements of British and European directives for medical device manufacture. (The Medical Device Directive requires a comprehensive technical file for every product.)

The use of IT can prove to be more of a hindrance than the blessing it is commonly advertised as if it is inappropriately implemented. Anecdotes from the lecture circuits often tell of companies who have invested large sums in systems that have created more problems than they solved, and experience from Rimmer Brothers certainly highlights one or two potential stumbling blocks. However, at the conclusion of this programme it is undoubtedly fair to say that IT has been successfully integrated into the company, and now provides tangible advantages over the methods employed prior to its development.

At the start of the programme the only computers in the company were those dealing with financial administration in London, and a single PC in Ross for word processing. The company now has a network of five PCs in Ross which are used for almost all quality document generation and storage, resourcing, purchasing, research and design. The company has some way to go before being able to create a genuinely paperless environment, but all those involved now appreciate and benefit from the advantages that computers can offer.

This does highlight one of the hurdles that has been encountered, namely a reticence to embrace new technology. There are still those in the company who regard computers as a financial burden, offering little return on their investment, and indeed it is difficult to quantify their advantages. It is also hard to convince those holding the purse strings that beyond the initial investment lies a gradual learning curve before any improvements in efficiency, and that once in place, an IT system requires regular administration and investment.

In terms of how IT has augmented the CE environment, its advantages can be seen throughout the last chapter. CAD has allowed for faster and more complex product development, better communication of concepts both within the team and with customers and suppliers, and easier quality document generation and maintenance. It must be said that at the start of the programme the use of CAD slowed development, but as the designers have become more familiar with its capabilities speed has increased.

To illustrate this effect, design and 3D modelling of the light duty handle took 2-3 weeks, after which point a further 3-4 days was required to convert the 3D solid model into meaningful 2D drawings for manufacture. By contrast, the 25 manufactured parts of the HLS took in total a similar length of time, whilst 2D drawings were created in only a few minutes, and a full assembly drawing was easily built up from these existing files (Figure 6.e)

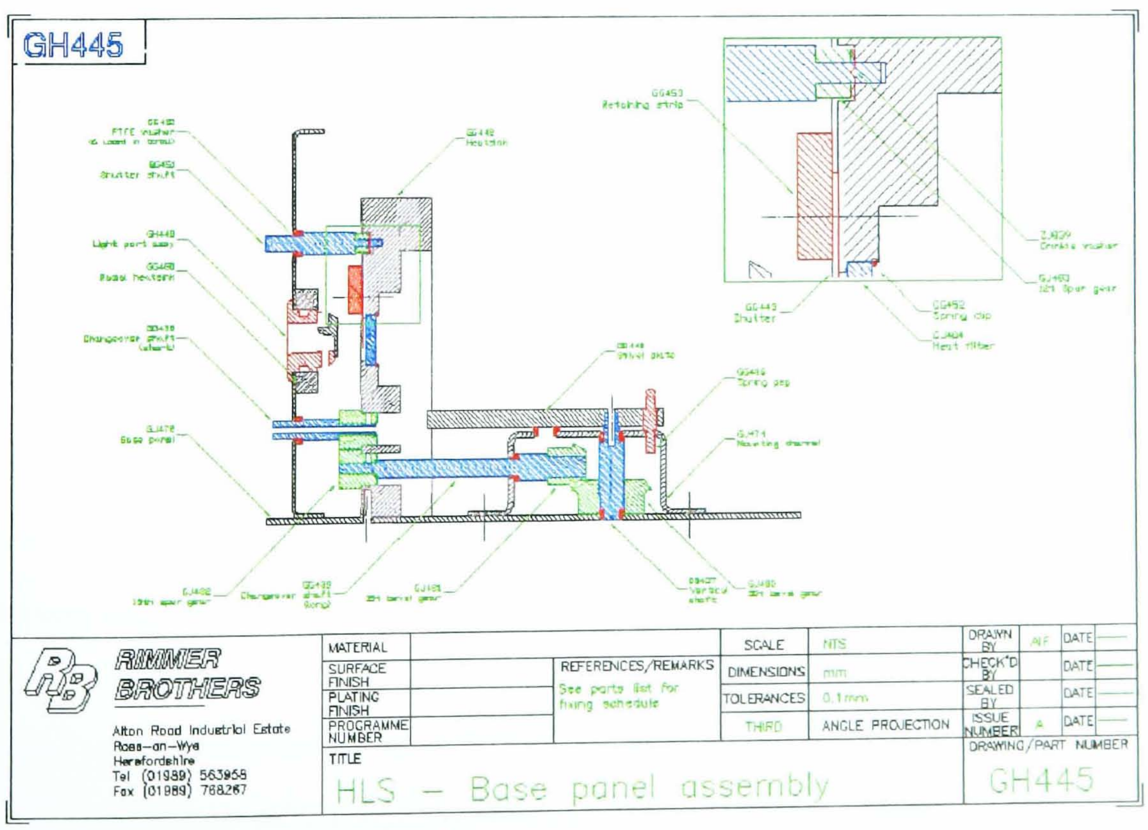
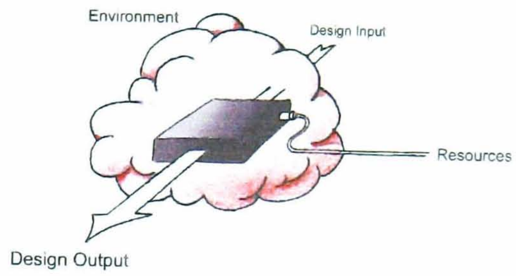


Figure 6.e HLS Assembly Drawing

Networking of on site computers has also helped to speed up development by giving the designer access to purchasing records and a regularly updated supplier database. Using simple search tools, information regarding a particular supplier, or a type of product can be found rapidly. Similarly, relevant on-line design documentation can be searched out and viewed instantly.

6.3.2 Environmental Effects on Implementation



The factors (both positive and negative) affecting the selection and use of CE tools have been identified from research presented in Chapter 2 and in the light of the results of this thesis as:

- Size - number of employees
- Company culture: hierarchy, departmentalisation and communication
- Individual personalities
- Available funds
- Existing assets
- Batch size / production quantity
- Product type and complexity

Of these factors, the first four were observed to have affected implementation during this research.

6.3.2.1 Company Size

Company size has directly influenced the manner in which CE has been applied. As discussed in Section 2.1.3 the fundamental idea behind CE is to achieve parallel as opposed to serial development of a product. It is easy to see how this is achieved in large organisations, where representatives from various departments can be assigned to work together as a team. However, the size and consequent strain on resources in Rimmer Brothers prohibited the creation of a dedicated team approach since when members are involved in meetings, their own work cannot be delegated and simply grinds to a halt. This immediately promotes a negative attitude toward attendance, especially when a member finds that their specific input is not called upon during a particular meeting.

6.3.2.2 Company Culture

Whilst many of the factors listed above act as barriers to the use of certain CE elements, and limits on others, some points provide a genuine advantage over the larger company. Indeed, whilst large companies often use CE to aid inter-departmental communication, this was not seen to be as significant a problem for Rimmer Brothers: Although individuals within the company have defined job descriptions, in practice their day to day work can be much more diverse. Certainly within the Ross-on-Wye unit it is common for the quality manager or the technical manager to get involved in hands-on manufacture or assembly work. Equally, assembly and shopfloor workers are encouraged to offer opinion on how processes can be improved. This open communication culture has unquestionably aided the use of CE, and promoted the development of the fluid design team.

Conversely, communication between Ross and London, and within the London unit was much less effective. This highlights one area where it has been more difficult, and also more important to promote CE ideals: Essentially, the London office represents the front end of the company. This is where Rimmer Brothers interacts with its customers, either directly, or through their network of sales representatives. With the design department's relocation to Ross-on-Wye, it became harder to maintain frequent and meaningful dialogue between the customer and designer. As the trolley project demonstrated however, this has been successfully achieved through the inclusion of sales reps in early design meetings, and by visits to the product's working environment, in this case hospital operating theatres. The decision to relocate to Ross was made on the basis that much more frequent dialogue with manufacturing was required, and that as long as customer requirements were still being effectively met, making products easier and more efficient to manufacture would provide the greatest benefit for the company.

6.3.2.3 Individual Personalities

In Section 4.1.2 it was noted that resistance to change may hinder the integration of new ideas into the company. On reflection, this factor has not been as overwhelming as it could have been. There is a definite difference however, between the older and younger management approaches. Those who instigated and were heavily involved in the scheme demonstrated an enthusiastic and far sighted response to the new design process. Conversely, the more senior members of the management team, and also many of the longer serving shopfloor employees showed a dogmatic reaction to the ideas of CE. Had this attitude been more endemic, it is certain that CE would have failed to get off the ground.

6.3.2.4 Available Funds

Of the remaining factors affecting implementation, the amount of available funds is certainly the most influential. A large organisation embarking on a programme of process re-engineering is normally capable of allocating significant sums of money to provide for personnel and equipment. They may take on extra employees, and invest in comprehensive IT systems on the premise that they will in the long term recoup this investment by selling more products, or improving efficiency. Although this same foresight is required whatever size the company may be, the smaller the company the less ambitious they can literally afford to be. Rimmer Brothers have invested, with the initial aid of the DTI, in one extra salary and a desktop CAD system. Financial constraints prevented the consideration of installing video conferencing suites, bespoke electronic data management systems, or full blown parametric design and simulation software. Throughout this programme, it has been important to bare this fact in mind, and work with the company to achieve the most effect from the least financial input.

The use early in the programme of rapid prototyping (for the heavy duty handle, discussed in Section 5.1.2) provides a clear example of this. Although the RP handle was useful in evaluating the design, at £700 it was not a worthwhile expenditure when 3D modelling and more conventional clay models would have achieved the same result. It is unlikely that such a service would be used again unless its value could be more immediately justified.

6.4 Experiential Evaluation

This research has sought to describe the results of integrating CE into the novel environment of a small company. In doing so it has become clear that this environment indeed plays a role in how CE is accepted. However, closer analysis is now required as to what extent each of the environmental factors identified in the last section contributes, and consequently what objective conclusions can be drawn. Concurrent Engineering is both a philosophy and a methodology. Its use promotes a way of thinking, whilst its tools bring discipline to the way in which it is applied. The final evaluation presented here acknowledges this, and assesses its effects on both levels.

6.4.1 CE Philosophy

The original definition presented in Section 2.1 states that CE is a *systematic* approach to the integrated, *concurrent* design of products and their related processes. This approach is intended to cause the developers, from the *outset*, to consider all elements of the product *life cycle*. In essence, CE can be described as *Systematic & Pre-emptive.*

In contrast to large organisations, it has been shown that the factors discussed in the last section can conflict with these ideals: The fundamental issue is that *a systematic, pre-emptive approach to design requires more immediate resources*. The problems encountered due to this can be summarised as follows:

- Small companies have limited resources
- Small companies often foster a culture where foresight to see longer term advantages is ignored
- Documentation is not such an ingrained part of small company procedure and so requires additional commitment to maintain

These factors combine to inhibit CE acceptance, and prevent the use of many of the tools that may otherwise help to alleviate these very issues. Furthermore, poorly documented processes have hampered a financial assessment of the benefits of implementation.

The conclusion of this research is that in order to overcome this problem, it was necessary to prioritise precisely what the company hoped to achieve by implementation. In the case of Rimmer Brothers, it became clear at an early stage that shortening development time could be sacrificed at the expense of improving product quality. Only by making this decision could the resource equation balance, and the essence of CE work for the company.

6.4.2 CE Methodology

Referring to Table 6.A, a more detailed examination of cell E3 is required in the light of the discussion in Section 6.3.2. By relating individual CE tools (as introduced in Section 2.2) to each of the environmental factors, an analysis can be made of how the company affected the *method* of CE implementation. The basic binary relationship begun in Table 6.A would give some indication of the predominating factor (e.g. Does company size affect attempts to introduce DFM - yes or no?).

However, it is proposed that in order to quantify these effects, a translational matrix similar to those employed by QFD would help. Furthermore, just as QFD employs weightings to promote important factors, a more realistic result will be obtained by firstly suggesting how the environmental factors interrelate, and applying appropriate weighting values. For instance, if it were the case that available finances were proportional to company size, then a larger company would have more finances available and so company size would have a knock on effect beyond the immediate impact on CE tool choice.

Table 6.E shows environmental factor interdependence. For each variable identified in Section 6.3.2, its effect on other variables is indicated by a 1(can produce effect) or 0(has no effect). These values are averaged to provide an adjustment which is added to an initial weighting of 1. For instance, a change in product complexity could shift the product into a different market, thus affecting market rate of change, and could also impact upon production rates. A score of 2 out of 5 gives a weighting of 1+2/5 = 1.4

	CS	FR	PC	CC	MC	PR	Total	Av	Wt
Company Size (CS)		1	1	1	0	1	4	0.8	**1.8**
Financial Resources (FR)	0		0	0	0	1	1	0.2	**1.2**
Product Complexity (PC)	0	0		0	1	1	2	0.4	**1.4**
Company Culture (CC)	0	0	0		0	0	0	0	**1**
Market Rate of Change (MC)	0	1	0	0		1	2	0.4	**1.4**
Production Rate (PR)	1	0	0	0	0		1	0.2	**1.2**

Table 6.E Weighting Table

In arriving at these weighting, or 'biasing factors', it is important to stress that they are subjective ratings intended to promote a more realistic result, and not statistically based. Similarly, the dependence values in the table below are based solely on experiential, and not experimental results. Table 6.F shows the completed matrix of Biased Environment - Tool (BET) Relationships. Each environmental factor is scored against each CE tool on a 0-5 scale (0 = no effect, and 5 = dramatic effect) to suggest how important that factor is when considering use of the particular tool. For instance, the number of employees in a company bares no relation to the choice of whether or not to use CAD (0), but the complexity of the products being designed may well require its use (5).

	QFD	CAD/ CAM	MDT	DFM	EDM	RP	Subtotal	Weight (table 6.E)	**Total**
Company Size	2	0	3	1	3	1	10	1.8	**18**
Financial Resources	1	3	2	2	3	4	15	1.2	**18**
Product Complexity	2	5	1	1	4	3	16	1.4	**22.4**
Company Culture	1	0	3	0	2	0	6	1	**6**
Market Rate of Change	0	3	4	1	3	2	13	1.4	**18.2**
Production Rate	0	2	0	3	0	4	9	1.2	**10.8**

Table 6.F Biased 'Environment-Tool' Relationship

The totals presented in this table indicate which environmental factors have the largest impact on selection of the CE tools included in the analysis. They suggest that Product complexity is the single most important factor, with company size, finances and market also significant. Company culture has rated as the least significant. This is not particularly surprising since many of the tools included here work independently from its influence. Regard should of course be given to the previous section discussing the general CE ideology, where company culture plays a much more significant role.

6.4.3 Final Remarks

Rimmer Brothers has unquestionably benefited from participation in this scheme. The tangeable benefits can be summarised as:

- Reduced product cost
- Improved product functionality
- More predictable and traceable development process

The company has however not realised its aim of shorter lead times. That limited resources have necessitated this sacrifice is the single most significant result of this research.

The selection of CE tools was also substantially restricted by resource shortage, but also by company size and market sector, the last of which will have contributed to the decision to sacrifice lead time compression (had this been an electronics company, this sacrifice could probably not have been afforded). The one essential CE tool, that of multi-disciplinary teamworking, has been utilised in an unconventional, but highly successful manner. Characterised by informality and a loose 'fluid' structure, yet defined enough to maintain traceability, responsibility and a sense of team spirit, the fluid design team has succeeded in drawing together relevant expertise and instilling lifecycle considerations into designs at early enough stage to avoid downstream setbacks.

Experience from this research has demonstrated that with careful consideration of the specific needs, resources and culture within small companies, the fundamental ideology, and the techniques associated with concurrent engineering can be applied with very positive results.

It may be useful for companies in the planning stages of CE implementation to work through a similar BET analysis, thereby identifying their own significant environmental factors before selecting tools and techniques to implement CE.

6.4.4 Future Work

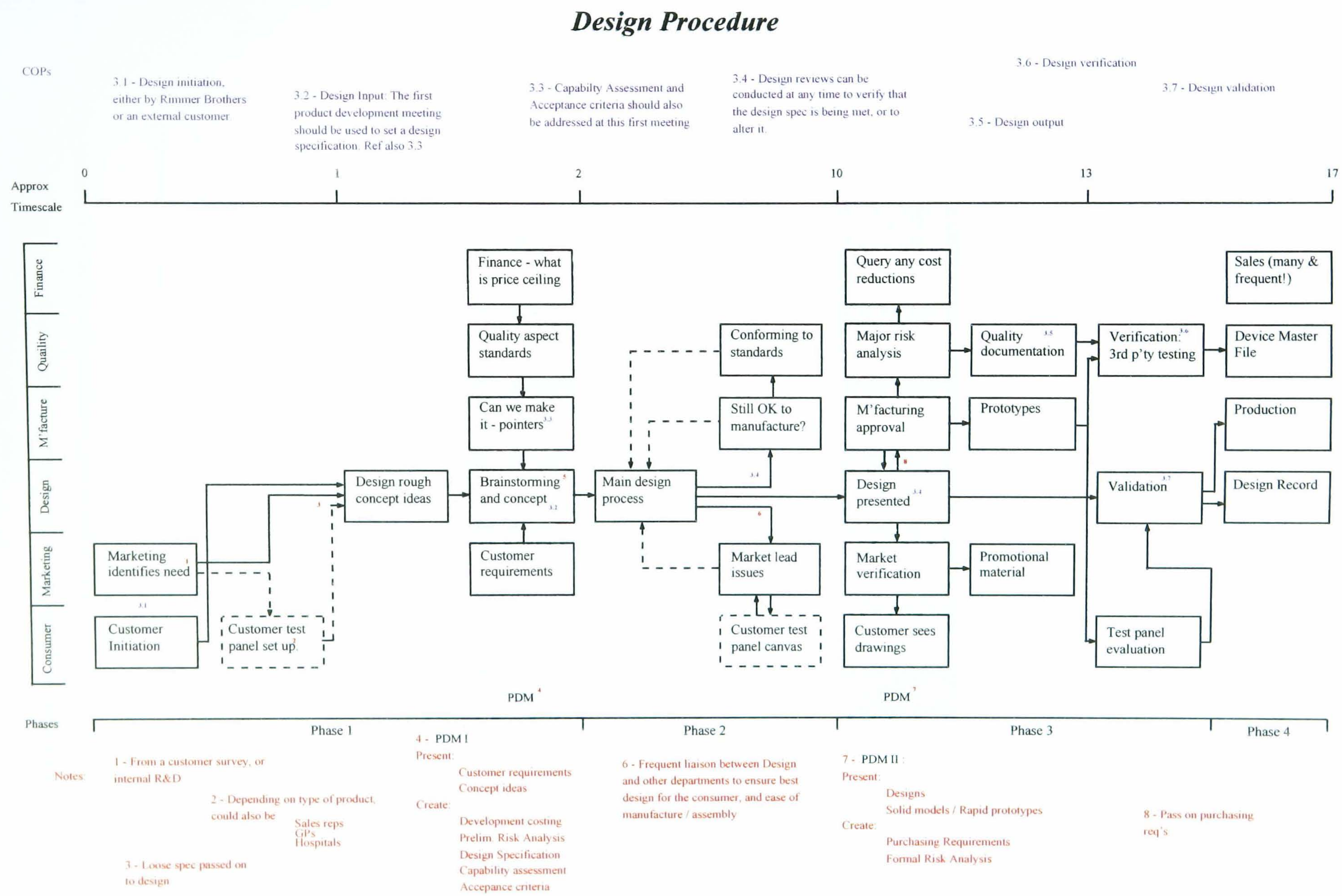
In Section 2.3.2 (pg29) some of the other research on CE use & adaptation was presented. This research fell into two categories: Case Study results of generic implementation in large companies, and Survey based results of implementation modes amongst a group of companies. Individual case studies are a useful source of detailed inside information, and this paper has contributed to this category of research. The advantage of an internal perspective allows for a far more comprehensive description and analysis as compared to a survey - which, however detailed, relies on the right questions being asked, and a representative response.

However, if the hypothesis that novel conclusions would be drawn from this thesis' research is to be accepted, it follows that no single case study has provided universally applicable results. In this respect this thesis is no different. It is proposed that the detailed conclusions of this research should now form the basis for further survey based study. By collating experiences from a number of similar projects it would be possible to draw reliable general conclusions regarding the adaptation of concurrent engineering to novel environments.

It will be interesting to see how over the course of the next few years Rimmer Brothers profits from the process changes made, and the products developed during this scheme. As with the extension of research to include other companies, only after expanding results to include many more projects within this company can the effects of this scheme be truly quantified.

Furthermore, although systems are now written into the company operating procedures to encourage their continued use, it is not known whether a gradual return to old working practices will be seen. Without financial returns yet attributed to the scheme, a degree of strategic planning and foresight is still needed on the part of those inheriting the work done so far to maintain the momentum of culture change and continuous improvement, and to avoid stagnation. At the time of writing, however, those responsible for the initiation of this programme are still firmly committed to both CE and the company's future, and are considering work on a similar scheme to build on the framework already in place.

Appendix A - Design Flowchart



Appendix B - Company Operating Procedure 02

The following text is taken from the company operating procedure for design, re-written to allow scope for CE inclusion in the process, and ensure documentation is maintained.

1. OBJECTIVE

To define responsibilities and procedures for controlling and verifying the design of products and to ensure specified requirements are met.

Note: This procedure covers the design of a new product or the major redesign of an existing product. Minor changes to a sealed design are covered in RB COP/03, Documentation and Change Control.

2. PLANNING & CONTROL

2.1 Responsibility & Personnel

2.1.1 The Technical Manager is responsible for all design and development work and will control these activities and the associated documentation through the Product Development Team of which he is the Chairman. He may delegate responsibility for certain actions as required.

2.1.2 The Product Development Team is comprised of selected Marketing, Finance, Quality, Design and Manufacturing Personnel from within the Company, whose formal meetings are minuted. The Chairman will assign tasks as required to team members and co-ordinate their work as necessary.

2.2 Design control & Documentation

2.2.1 All design work is controlled and recorded on the Design Record, RB Form 30 (Appendix I). The Technical Manager is responsible for the upkeep of this record and for ensuring that all its requirements are met. He will maintain a record of all Design Records.

2.2.2 Design records will be serially numbered and issued by the Technical Manager who will keep a record of all design projects initiated. The Quality Manager will allocate a part number to new products before completion of the design.

2.2.3 Full details of all design activities are to be recorded on the Design Record, with reference to relevant associated forms and/or minutes attached.

2.2.4 For projects reaching completion, the Quality manager is responsible for the creation and upkeep of a Device Master File (see para 4 below)

3. DESIGN PROCESS

3.1 Design Initiation

Relevant RB Forms	131	132	133	Appendices II, III, IV

3.1.1 Details of the initiator of the design are to be recorded in part 1 of the Design Record.

a. If it is initiated by RB the reasons for the design and or redesign will be recorded.

b. If it is by a customer, full details of that customer (name, address, tel. no., etc.) will be recorded.

3.1.2 Potential customers / users should be contacted at the earliest possible stage, and any feedback recorded and analysed on Forms 131 & 132

3.2 Design Input

Relevant RB Forms	134	135	136	Appendices V, VI, VII

3.2.1 A full design specification, reflecting the product requirements of the end user, will be recorded on Form134, and referenced on the Design Record. The Technical Manager is responsible for confirming all parts of the specification with the initiator of the design and for resolving any incomplete, ambiguous or conflicting requirements. The following areas will be addressed, a detailed breakdown of which can be found on Form 134b in the form of a check list.

Section a **Design Requirements**

Will include a description of the product and its intended use, and details of all relevant design features (e.g. Tolerances, Power source, Control systems, etc.)

Section b **Manufacturing requirements**

Note on prototype quantities, materials and production restrictions

Section c **Quality requirements**

Highlighting relevant standards, safety, testing and reliability requirements and proof of compliance with Annex 1 of the Medical Devices Directive 93/42/EEC through Risk Assessment.

Section d **Marketing requirements**

Defines required time to market, packaging and promotional requirements

Section e **Finance requirements**

An analysis of critical cost restrictions. A full analysis of development costs should be recorded on form 136

Section f **Other requirements**

3.2.2 The design input may be amended at any time of the authority of the Technical Manager as a result of design reviews. Any amendments will be minuted on Design Review Form 138, attached to and referenced on the Design Record.

3.3 Capability Assessment & Acceptance Criteria

Relevant RB Forms	137	Appendix VIII

3.3.1 Before Design work is started the Technical Manager will review the design input to assess RB's capability to meet specified requirements. Particular consideration will be given to the following points

a. **Company Objectives Compatibility**

Confirmation that the proposed product concurs with RB's company objectives

b. **Design Potential**

Assessment of whether the project is within RB's design capabilities, bearing in mind the knowledge and experience in the various disciplines, or whether outside assistance will be required. The identification of any outside assistance will be minuted and attached to the Design Record.

c. **Manpower and Skills**

Assessment of adequacy of existing manpower and their skills, identifying any new skills or retraining required.

d. **Development and Manufacturing Resources**

Assessment of adequacy of existing resources, identifying the requirement for sub-contract work or additional resources.

e. **Material Sourcing and Availability**

Identification of any material not normally used by RB and its sourcing.

f. **Test/Measurement/Inspection Facilities**

Assessment of adequacy of existing facilities, identifying any requirements for new measurement techniques, new equipment or facilities of third party testing.

Is the preliminary Risk Assessment acceptable?

Can RB comply with identified standards?

g. **Market capability**

Confirm market size and likely retail price are acceptable. Ensure RB can supply to market in time.

3.3.2 Account of this assessment will be entered on the Design Record. **Only once all of the above criteria have been approved by the Technical manager can the design process proceed beyond this stage,** and an Activity plan for the appropriate activities will be initiated. The Activity plan will outline the following:

- the activities required to produce the required design.
- personnel responsible for the implementation of the various activities
- the resources required for the implementation of the various activities
- the proposed time scale required
- design review points

3.3.3 The original assessment may require amendment in the light of design reviews. Records of any reassessments made and their conclusions will be minuted, attached to and recorded on the Design Record.

3.4 <u>Design Review</u>

Relevant RB Forms	138	Appendix IX

3.4.1 When necessary the Technical Manager will carry out design reviews with any of the personnel and/or sub-contractors involved in the design to:

a. Verify that design input is being met.
b. Identify and anticipate problem areas and inadequacies.
c. Carry out a 'risk analysis' and identify any potential hazards.
d. Agree any amendments to design input or capability assessment.

3.4.2 All reviews will be minuted on the Design Review Form 138, attached to and referenced on the Design Record.

3.5 <u>Design Output</u>

Relevant RB Forms	139	140	141	Appendices X, XI, XII

3.5.1 Design output will list all the quality documents generated to meet the design input. These will include, as appropriate, drawings, parts lists, manufacturing instructions, assembly diagrams, test and inspection specifications, user information sheets, circuit diagrams etc. The creation of these documents is the responsibility of the person(s) assigned to the design by the Technical Manager (see para. 2 above).

3.5.2 The Quality Manager is responsible for allocating part/document numbers (see RB COP/20) to all quality documents and initiating the control of these documents (see RB COP/03).

3.6 <u>Design Verification</u>

Relevant RB Forms	142	Appendix XIII

3.6.1 The formal design verification ensures that the product complies with the design specification, and will include, as appropriate, records of:

a. Prototype tests to evaluate the performance of the product and separate components of it against the design input, taking into account any amendments as a result of design reviews. All tests will be recorded on Form 142 and referenced on the Design Record.

b. Safety and/or Third Party testing. Details of any external test house and reference to their reports will be recorded on Form 142.

c. Compliance to specified standards (see para 3.2.1.c above)

d. Clinical investigations.

e. Risk analysis.

3.6.2 Manufacturing Instructions, where applicable will be written based on experience during the manufacture of prototypes. These instructions will be verified during the manufacture of the first batch of the product, which will invariably be a restricted batch.

3.7 <u>Design Validation</u>

The final stage of the design process ensures that the product conforms to consumer requirements, and is thus fit for its intended use. The design will then be 'sealed', and released for production after addressing the following :-

- All quality documents will be approved by the Technical Manager and recorded as such.
- The Device Master File will be completed in line with the requirements of the Medical Devices Directive 93/42/EEC and a Declaration of Conformity compiled for approval.
- Notification of the intent to place the device on the market, whether new or substantially modified, to the Competent Body or Notified Body as appropriate.
- Approval will be given for production to proceed, detailing initial and, if appropriate, subsequent quantities.
- Approval of any new suppliers and/or sub-contractors designating the inspection level for their deliveries.
- Directions for the distribution of quality documents.

3.8 <u>Design Changes</u>

Once the design has been sealed and is in production, minor design changes will be controlled as detailed in COP/03. Major design changes will be subject to the controls details in this procedure above.

4. DEVICE MASTER FILE

4.1 The Quality Manager is responsible for the creation and subsequent maintenance of a Device Master File for all products where appropriate. Medical Device Master Files will be required to comply with Medical Devices Directive 93/42/EEC Annex VII para. 3 and must include the items marked 🕮

4.2. It will consist of the following documents where applicable:-

- 🕮 Inclusion of, or reference to all Design Records with all relevant planning and design documents attached or referenced
- 🕮 A Risk Assessment
- 🕮 A general description of the product and its operation, including attachable devices.
- Any Technical Notes relevant to the product.
- Parts Lists
- 🕮 Manufacturing Instructions
- 🕮 Assembly diagrams
- 🕮 All relevant drawings and specifications
- 🕮 Details of labelling
- 🕮 User Information sheets/ Instructions for use

- 🕮 Copies of any Third Party test reports and approval certificates including proof of performance with attached devices, if appropriate.
- 🕮 Sterilisation requirements - if appropriate
- Declaration of Conformity

4.3. All quality documents will be controlled in the appropriate Master File Lists (see COP/03).

4.4 Separate files, or sections in existing files, will be established for entry of the following information:

- All Batch Manufacture Records (see COP/06a)
- All relevant Test Result Sheets (see COP/07)

4.5 All superseded quality documents relevant to the device/product will be clearly stamped 'CANCELLED' (see COP/03) and will be filed in alpha/numeric order by part codes.

5. RECORDS

5.1 Device Master Files will be retained for at least the lifetime of the device/product plus 5 years.

5.2 Design Records for devices that do not go into production will be retained for a minimum of 5 years at the discretion of the Technical Manager.

Appendix C - Trolley Design Specification

Design Input	COP02 3.2.1	Appendix/Reference No.	

Design Specification

Product	Project	Initiation Date
CCTV Trolley	DR7	

Section 1	Design requirements	**Section 4**	Marketing requirements
Section 2	Manufacturing requirements	**Section 5**	Finance requirements
Section 3	Quality requirements	**Section 6**	Other requirements

Product Design Specification page	1	of	2	

Section	Critical ✓/✗	Specification *(Reference Form 134b)*	Amendment No.	Amendment Date
1.1/2	✓	A wheeled trolley for storage and use of endoscopic equipment in an operating theatre environment		
1.2	✓	Used in the operating theatre to carry CCTV equipment, including monitor (20”), light source, video recorder and camera.		
1.4	✓	Drawer must accommodate VCR tapes & camera. Base unit to incorporate IEC distribution panel and isolation transformer		
1.5		Cf. old trolley design		
1.6	✓	Mains power input, to IEC type output sockets on trolley rear via optional isolation transformer		
1.7/8		Moving parts (apart from wheels!) associated with swing out monitor arm, capable of being mechanically moved to an position, and balanced to remain where placed. Drawer to run more smoothly		cont...

Section	Critical ✓/✗	Specification (*Reference Form 134b*)	Amendment No.	Date
1.9		More elegance cf old design. Research alternate finishes including anodising, new colour schemes.		
1.10	✓	Must be easy to handle and operate by female		
1.11		Cleaning to be achieved using alcohol or similar		
1.14		RB insignia, possibly drawer lock direction indicator		
2.1		Two fully working prototypes		
3.2		Minimal maintenance in field. Comprehensive spares		
3.3		available		
	✓	EMC compatible		
3.4	✓	Compliance with MDD with intention of ce marking		
3.6	✓	Training & instructions to be provided		
4.1		Third party safety / EMC testing expected		
4.2		Stock to be available Feb 1997		
5		Easily fitted protective cover for transit		
6		Costs to be post analysed - record as incurred		
		Facility for additional components:		
		Security brackets		
		Camera holder		
		Camera/cable storage		
		Gas bottle holder		

Appendix D - Published Papers

The following paper was presented & published in it's original format at

- 1997 Design to Manufacture in Modern Industry conference, Slovenia

and in a similar format at

- 1997 TCS Seminar on Product Design, London
- 1997 National Conference on Manufacturing Research, Glasgow

Tailoring Concurrent Engineering to Small Companies

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ABSTRACT

Much has already been written on the subject of simultaneous, or concurrent engineering (CE), and this is now a recognised and widely practised method of product development. It is still, however, mainly the preserve of large and medium sized companies *(Melling et al)* (100+ employees) amongst which it originated around ten years ago. CE's principle tenets of reduced product development time and improved quality are, however, equally relevant to smaller companies, and the importance of realising and acting upon this knowledge cannot be understated if they are to survive in an increasingly competitive environment.

This paper presents the progress of a collaborative Teaching Company Scheme initiated in 1994 between Middlesex University and Rimmer Brothers, a small medical instrument manufacturer. The aim of the scheme is to implement and monitor a number of CE tools and techniques within the company to improve market share and ensure its long term competitiveness. This has been achieved through the placement of two 'associates' working full time within the company as product and process designers, with the expert knowledge and backing of the college. In the light of experience, this paper will analyse the relevance of such tools as computer aided design & manufacture, multi-disciplinary teams, design for manufacture and quality function deployment, whilst providing a qualitative opinion on how to implement the broad philosophy of concurrent design within a small company.

1 INTRODUCTION

It must be true to say that there are far more small companies (of 100 or less employees) in a nation than there are large; and that competition within this sector is no less important or hard fought than it is between the relative handful of multinationals. It seems strange, therefore, that many remain oblivious, or unaware of the tools and philosophies employed by their larger competitors to gain advantage. Research conducted by Melling in 1995 found, for example that

> "Only 21% of companies undertaking design and manufacture used multi-disciplinary teams"

This lack of tack up is due, in the main part, to the focus of research in this area, initiated more often than not by and for such organisations. There is also a perception amongst small companies that the physical and managerial costs of implementing such techniques would be beyond their abilities.

The reality is, however, that as the millennium approaches, those companies large or small that fail to appreciate and accommodate these ideas will find it increasing hard to survive, as they are beaten to the market place by competitors with cheaper and better products.

2 CONCURRENT ENGINEERING

Perhaps the most universal and fundamental of these philosophies is that of concurrent engineering (CE). Although even today experts argue over the exact definition of CE, its basic principles lie at the heart of this global revolution in manufacturing.

CE originated in the USA during the 1980s in response to the increasing domination of Far Eastern companies in the global market. The term was first defined in an American Defence Advanced Research Projects Agency report as…

> "…a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support."

The report continued…

> "This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept, through disposal, including quality, cost, schedule, and user requirements." *Institute of defence analysis ('86)*

There are two fundamental points to draw from this definition. Firstly, that design should take in to consideration not just the needs of the consumer, but every part of the product's life; and secondly that this should be practised concurrently, from the outset. Prior to this, product development followed a serial, or sequential approach - as it still does in many organisations -

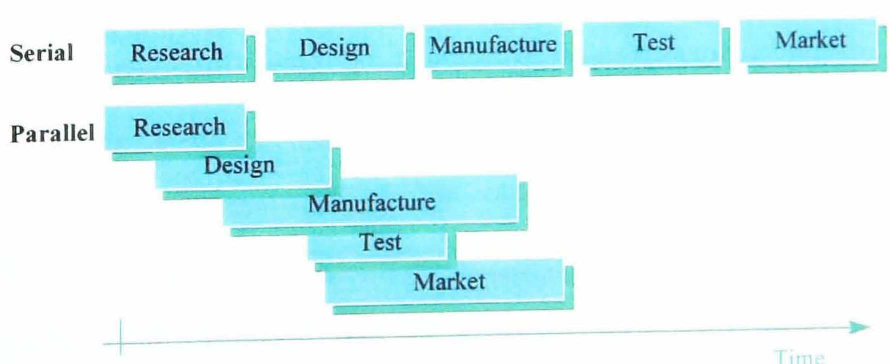

Figure 1

By overlapping departmental input, not only is lead time substantially reduced (figure 1), but the quality of the finished product is improved. Syan quoted much evidence of this within large companies:

"Rolls-Royce reduced the lead-time to develop a new aircraft engine by 30%; McDonnell Douglas reduced production costs by 40%" *Syan ('94)*

CE can be seen as a guiding principle, supported by a host of tools, some or all of which can be of use, depending upon the needs of the company. The following list presents some of the more widely practised of these tools:

- Design for manufacture / assembly / generic 'design for x'
- Multi-disciplinary teams
- Quality function deployment
- Total quality management
- Just in time stock control
- Computer aided design & manufacture
- Electronic data management / interchange

It is important to realise that, although these concepts can all help in achieving the goals of CE, the most important factors in successful implementation are open communication, and support for change throughout the whole company, not least from senior management.

3 THE COMPANY

Rimmer Brothers has been the test case company for the ongoing research presented in this paper. Founded 74 years ago as a diagnostic instrument manufacturer for the medical industry, operating from a small London office, the company now has around 40 employees, split between its main administrative offices, and a precision manufacturing facility in Ross-on-Wye.

From the outset the company has endeavoured to stay at the forefront of its chosen specialities in illuminated and electro-cautery equipment. However, in recent years the company has become increasingly aware of the need to update its ageing product range to maintain competitiveness in an increasingly technological field.

To this end, in 1994 they enlisted the help of Middlesex university in a collaborative partnership with the Department of Trade and Industry. The three year project that was set up aimed to analyse the current business practices within the company, and consequently, through the placement of two graduate engineers, implement techniques to improve the process of product design, whilst conducting a series of design projects.

4 THE PROBLEM

The initial study of the company revealed several major problems to address. Primarily, there was no formal procedure for design. New product introduction was the result either of a perceived need, commonly as a reaction to the initiative of competitors, or of a particular customer's request - on a commission basis. Once initiated, design would progress erratically as and when resources were deemed available. As the responsibility of one or two individuals, documentation of the process was regarded as time consuming, and largely unnecessary. The overall timescale from concept to finished product could lie anywhere between two weeks, and two years - depending on the perceived urgency. However the actual amount of time devoted was necessarily short, since the company did not have a dedicated design engineer.

4.1 Evaluation of original development system:

Advantages

- Potential for rapid design, from idea to product in as little as two weeks
- No need for extra personnel
- Part visualisation & testing intrinsic
- Some regard to ease of manufacture

Disadvantages

- Ties up manager in non-managerial tasks (designing / making)
- Creation or modification of drawings long and laborious
- Insufficient market testing or analysis
- High chance that redesign may be necessitated
- Insufficient consideration given to use of other concepts or materials.
- Distinct lack of traceability.
- Lack of regard for ease of manufacture/assembly

- Comparatively late product introduction

5 THE SOLUTION

Having defined and acknowledged the problems, an approach to tackling them was formulated. Two basic requirements were identified:

- Reduce development times
- Improve product quality

In the second of these, the term quality refers not only to fitness for purpose, but encompasses such concepts as ease of manufacture & assembly, and cost optimisation. On the surface, a generic implementation of CE would seem to be appropriate, however it is immediately apparent that the size and nature of the company prohibited this. Indeed, to consider such concepts as QFD would be completely inappropriate on such a small scale, and with limited resources. However, the applicability of CE's basic principles remained unquestioned.

Hence, over the past two years, a careful and gradual introduction of elements of CE has been attempted. The specific issues affecting the choice of these elements relate, as stated, to company size. It should be noted that they are by no means all negative. The intimacy, and informal nature of a small company has been seen to aid communication, whilst the flat hierarchy is an essential prerequisite of transparency and lack of bureaucracy. These very same elements, however, have also provided problems in terms of reluctance to change working practices that are perceived to have worked successfully for many years. On a more practical level, turnover and minimum order quantities from suppliers make the application of concepts such as 'Just In Time' stock control almost impossible. Also on the financial issue, funding for high cost tools including Electronic Data Interchange; Video Conferencing; and Rapid Prototyping is not justifiable.

The first, and most important step was the setting up of a design team, with representatives not only from each discipline within the company, but also spanning the hierarchical ladder from senior management to shop floor, thus propagating the cultural change throughout the company. Meeting regularly to discuss project progress, this has provided the necessary simultaneous consideration of the most important stages of the product's life-cycle. Manufacturing, assembly, finance and marketing are all represented. The voice of the customer receives a much higher profile through the inclusion of sales representatives and test panels.

Originally, the team was made up of seven members plus a university representative, however the logistics of organising meeting dates (bearing in mind the company's co-location) hindered progress, with meetings taking place perhaps every 2-3 months. Recently it was decided to switch to a two-tier approach - the team now consisting of a core of four, with the expertise of other members called upon as and when required. Meetings now take place monthly, whilst everyone involved is kept up to date by means of minutes. A flowchart of the new design process was created to help identify responsibilities, and is presented in figure 2:

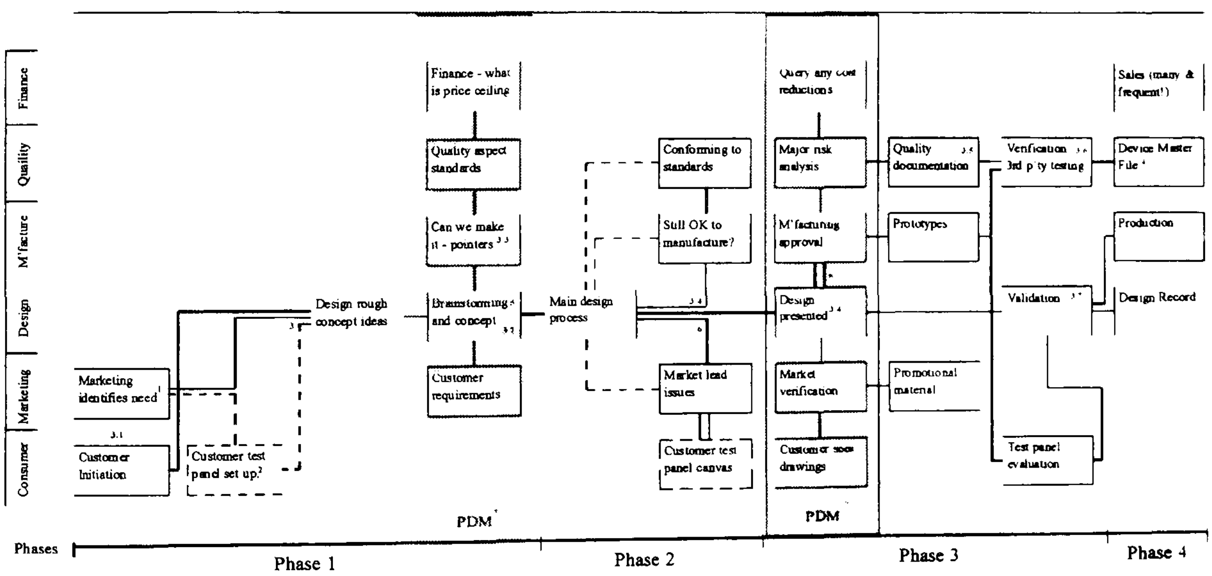

Figure 2

The second major change has been the installation of IT support in the form of computer aided design; a database of over 800 potential suppliers and the transfer/creation of all quality documentation including serial numbered labelling to computer. CAD has facilitated the rapid and low cost visualisation of a number of design concepts using rendered 3D solid modelling, whilst aiding the accurate transfer of ideas between team members and to manufacturing. It is the ultimate aim to complete this route with the integration of computer aided manufacture.

Organisation and traceability have been vastly improved, with the creation of detailed documentation now intrinsic in the design process. These factors have also incidentally eased the company's move toward ce ('Communitee European', not concurrent engineering!) marked products.

5.1 Evaluation of new development system

On the face of it, these changes would seem to be an unqualified success, but just how far they have satisfied the original objectives requires closer consideration:

Advantages

- Product visualisation via 3D modelling
- Various concepts can be modelled and compared early in the design process
- Drawings incidentally generated during modelling, & changes easier to make
- Manager free to manage
- Formal documenting of design process
- Consultation with other departments & customers should result in a better quality product

Disadvantages

- 1 extra salary
- Designer lacks 30 years of experience, and so must rely heavily on advice from other team members regarding manufacture / materials etc. This can result in time lost exploring avenues that would otherwise have been immediately discounted.
- Consideration of CE tools such as design for manufacture, design for assembly, and quality function deployment can only serve to slow down the average length of the design process

This last point is part of a quite complex equation affecting lead times. To date, two design projects have been conducted, and experience from them leads the author to several conclusions. Firstly, as stated, where before little regard was given to optimisation for manufacture, cost and intended purpose, the time now spent collecting data, discussing options, and considering these factors can only serve to slow down the development process. At the same time this scrutiny should reduce the likelihood of delays due to late design changes (whilst CAD would speed up any such alterations), but the relevance of this situation is proportional to product complexity, and has rarely been a major problem (compared with the knock-on effects of designing a car, for instance). Furthermore, whilst there is now an extra person, devoted to product development, he is also responsible under advisement, for manufacturing and assembly process design due to a lack of resources, hence a truly simultaneous process is not possible, and much of the benefit of time compression is lost. Finally, the implementation of any new system takes time to adjust to, as those involved are brought up to speed by training and experience.

6 CONCLUSIONS

A graph suggesting the recorded and predicted general effects of the scheme is presented below (figure3)

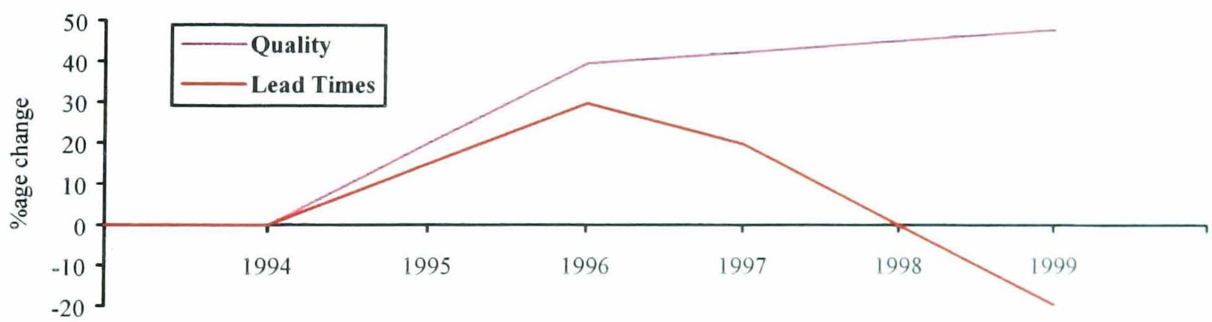

Figure 3

Overall, whilst the rate of new product introduction may have increased, the primary objective of reduced lead times has not yet been fulfilled. Perhaps more fundamentally, though, the quality of the finished products has improved in virtually every respect. There is still over 12 months remaining on the scheme, and it is hoped, as illustrated above, that both objectives will be achieved as the company culture continues to improve. As long as Rimmer Brothers continue to support the integration of modern techniques and improvements, the outlook for the company's future is very good.

REFERENCES

Melling, Koshal et al 1995 *The use of concurrent engineering in small to medium sized enterprises*

C.S.Syan and U.Menon 1994, *Concurrent Engineering. Concepts, implementation & practice*

D.Grace and S.Billatos 1992 *Application of Concurrent Engineering in the redesign process(Published in Design Engineering vol.51)*

Carter and Baker 1994 *Concurrent Engineering*

Appendix E - References

[1] Fisher, Douglas (1992); *The Industrial Revolution* pg44, St Martin's Press ISBN 0-333-37935-7

[2] Stearns, Peter N (1998); *The Industrial Revolution in World History* pg28, Westview Press ISBN 0-8133-3481-0

[3] Stearns, Peter N (1998); *The Industrial Revolution in World History* pg27, Westview Press ISBN 0-8133-3481-0

[4] Stearns, Peter N (1998); *The Industrial Revolution in World History* pg55, Westview Press ISBN 0-8133-3481-0

[5] Taylor, F W (1964); *Scientific Management Comprising Shop Management, The Principles of Scientific Management, Testimony before the Special House...* pg140, Harper & Row (No ISBN)

[6] Prinz F B (1991); *Creating Products in the Next Generation Design and Manufacturing Environment* pg17, The Christopher Hinton Lecture, The Fellowship of Engineering ISBN 1-87163414-8

[7] Parsaei, H R & Sullivan, W S (1993); *Concurrent Engineering - contemporary issues and modern design tools* pg24; Chapman & Hall ISBN 0-412-46510-8

[8] Parsaei, H R & Sullivan, W S (1993); *Concurrent Engineering - contemporary issues and modern design tools* pp24-26; Chapman & Hall ISBN 0-412-46510-8

[9] Oppenheim, P (1991); *The New Masters - can the west match Japan?* Pg27; Business Books Ltd. ISBN 0-09-174693-0

[10] Roberts, J M (1993); *Shorter Illustrated History of the World* pg458; Helicon ISBN 1-85986-053-2

[11] Christensen, C M (1996); *The Innovator's Dilemma* pg171, Harvard Business School Press ISBN 0-87584-585-1

[12] Taguchi G (1986); *Introduction to Quality Engineering* pg 1; Asian Productivity Organisation ISBN 92-833-1084-5

[13] Taguchi G (1986); *Introduction to Quality Engineering* pg 1; Asian Productivity Organisation ISBN 92-833-1084-5

[14] Hartley J, Mortimer J (1991); *Simultaneous Engineering* pg81; Industrial Newsletters Ltd ISBN 873381-01-8

[15] Petersen P B (1999); *Total quality management and the Deming approach to quality management* pp 483-4; Journal of Management History Vol 5 No 8 MCB University Press 1355-252X

[16] Gitlow H, Oppenheim A, Oppenheim R (1995); *Quality Management: Tools and Methods for Improvement*; Irwin (from ref13)

[17] Corbett J, Dooner M, Meleka J, Pym C (1993); *Design for Manufacture* pg149

[18] Abbot G (editor) 1996; *Advanced Manufacturing: ICAF Industry Study Report1996* pg4; National Defence University Press [published on-line at www.ndu.edu/ndu/icaf]

[19] Leitner P M 1999; *Japan's post war economic success: Deming, quality, and contextual realities* pg502; Journal of Management History Vol 5 No 8 MCB University Press 1355-252X

[20] (1998); *The Electronic Times*;

[21] Ettlie J, Stoll H (1990), *Managing the Design-Manufacturing Process*, McGraw-Hill

[22] Abbot G (editor) 1999; *Advanced Manufacturing: ICAF Industry Study Report 1999* pg3; National Defence University Press [published on-line at www.ndu.edu/ndu/icaf]

[23] Winner R I, Pennell J P, Bertrand H E, Slusarezuk M M G (1986); *The Role of Concurrent Engineering in Weapons Systems Acquisition*; Institute of Defence Analysis Report R-338

[24] Boothroyd G (Aug 1988); *Estimate costs at an early stage* pg 54; American Machinist 132 Penton Publishing Inc; ISSN 0886-0335

[25] Gatenby DA, Foo G (1990); pp 2-13 AT&T Technical Journal 69 (3)

[26] Whitney D E (1990); pp 3-13, Research in Engineering Design (2)

[27] Syan C S & Menon U (1994); *Concurrent Engineering - concepts, implementation & practice* pg 8; Chapman & Hall; ISBN 0 412 58130 2

[28] Dixon J R, Duffey M R (June 1988); *Quality is not accidental - it's designed*; New York Times

[29] Suh N P (1990); *The Principles of Design*; pp 40-42 Oxford University Press (NY)

[30] Hartley J & Mortimer J (1991); *Simultaneous Engineering - the management guide to successful implementation*; Industrial Newsletters Ltd ISBN 1 873381 01 8

[31] Carter D E & Baker B S (1992); *Concurrent Engineering - The product development environment for the 1990s*; Addison Wesley Publishing Co Inc ISBN 0-201-56349-5

[32] Siegal B (1991); Industrial Engineering 23 (12) pp 15-19

[33] Gatenby DA, Foo G (1990); pp 2-13 AT&T Technical Journal 69 (3)

[34] Lawson M & Karandikar H M (March 1994); *A Survey of Concurrent Engineering*; Journal of Concurrent Engineering pg3 vol2 #1 ISSN1063-293X

[35] Narraway R (1994); *Concurrent engineering sets the pace in computer aided design*; Design Products & Applications pg 21 Dec 1994

[36] DTI/CIMdata (1994); *Product-data management* pg12; Dept of Trade & Industry DTI/Pub 1294/3K/4/94

[37] Abbot G (editor) 1996; *Advanced Manufacturing: ICAF Industry Study Report 1996* pg9; National Defence University Press [published on-line at www.ndu.edu/ndu/icaf]

[38] Hauser J R & Clausing D (1988) *The House of Quality* pp63-73; Harvard Business Review, May-June 1988

[39] Hartley J & Mortimer J (1991); *Simultaneous Engineering - the management guide to successful implementation* pg 63; Industrial Newsletters Ltd ISBN 1 873381 01 8

[40] Syan C S & Menon U (1994); *Concurrent Engineering - concepts, implementation & practice* pg 94; Chapman & Hall; ISBN 0 412 58130 2

---

[41] Hartley J & Mortimer J (1991); *Simultaneous Engineering - the management guide to successful implementation* pg 32; Industrial Newsletters Ltd ISBN 1 873381 01 8

[42] Syan C S & Menon U (1994); *Concurrent Engineering - concepts, implementation & practice*; Chapman & Hall; ISBN 0 412 58130 2

[43] Booth J (1996); *Business Competitiveness and Change Management;* Seminar

[44] Booth J (1996); *Business Competitiveness and Change Management;* Seminar

[45] Lawson M & Karandikar H M (March 1994); *A Survey of Concurrent Engineering;* Journal of Concurrent Engineering pg 4 vol2 #1 ISSN1063-293X

[46] Reshef Y (1999); *Elton Mayo & The Human Relations Movement,* University of Alberta [published on-line at http://courses.bus.ualberta.ca/orga432/mayo.htm]

[47] Lawson M & Karandikar H M (March 1994); *A Survey of Concurrent Engineering;* Journal of Concurrent Engineering vol2 #1 ISSN1063-293X

[48] Poolton J & Barclay I (1996); *Concurrent Engineering assessment; a proposed framework* pg321; Proc. of the Inst. of Mech. Eng. Pt B Journal of Engineering Manufacture V210 N B4

[49] Poolton J & Barclay I (1996); *Concurrent Engineering assessment; a proposed framework* pg321; Proc. of the Inst. of Mech. Eng. Pt B Journal of Engineering Manufacture V210 N B4

[50] Poolton J & Barclay I (1996); *Concurrent Engineering assessment; a proposed framework* pg325; Proc. of the Inst. of Mech. Eng. Pt B Journal of Engineering Manufacture V210 N B4

[51] Yan H S & Jiang J (1999); *Agile Concurrent Engineering*; Integrated Manufacturing Systems v10/2 pg103 ISSN 0957-6061